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TABLES FOR THE IDENTIFICATION OF ORE MINERALS BY X-RAY POWDER PATTERNS*

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INTRODUCTION

This paper presents *x*-ray powder diffraction data for most of the ore minerals. The patterns have been classified in such a way that an unknown mineral may be identified by its pattern, provided it is contained in this collection. Much of the work on the project was carried out at Harvard University during the years 1935-1937. Since then, data have been accumulating, and as there is an almost unlimited amount of work that could be done it has been difficult to choose a suitable point at which to stop for purposes of publication. The collection and classification as they now stand have been found to be most useful in the mineralogical study of ores. They have been in laboratory use for three years during which time they have been checked, revised and enlarged.

Dr. Harry Berman and Dr. L. C. Graton of Harvard University are largely responsible for the progress that has been made on this project. Dr. Berman made available *x*-ray equipment, supplied many mineral specimens from museum collections, provided a classification of the

* Contribution from the Department of Mineralogy and Petrography, Harvard University, No. 250 in collaboration with the Laboratory of Mining Geology.

sulphide minerals that has been used as a basis for the comparison of powder pattern types, and has been most generous with his assistance throughout. Dr. Graton made available in the Department of Mining Geology all the facilities of that progressive laboratory, including spectrographic, microscopic and other special equipment, and a very complete collection of polished sections of ore minerals. This department supplied funds for making two precision powder cameras, for engraving and mounting a scale with which to measure spacings directly in angstroms, for assembling a micro-drill, and for spectrographic and *x*-ray materials. For the above and much more the writer is indebted to Dr. Berman and to Dr. Graton.

The basis for the present work was established by Hull,¹ in 1919, who showed that every crystalline substance gives a unique powder pattern. He also established conclusively that the same substance invariably gives the same powder pattern and that in a mixture of substances each substance produces its characteristic pattern independently of the other. The research staff of the Dow Chemical Company have demonstrated that it is possible to classify a large number of powder patterns in such a way that one may speedily recognize an unknown crystalline substance by its powder pattern. Kerr² has pointed out the possibilities of the powder pattern method as applied to the identification of opaque minerals. This method has been applied to the copper-bearing minerals by Waldo,³ but to date no systematic collection of ore-mineral patterns has appeared, although some of them have been listed among those classified by the workers in the Dow Chemical Company laboratory.

SOURCE OF MATERIAL

In preparing any collection of powder patterns for use as standards it is absolutely essential to secure authentic material. One of the greatest dangers is to accept a powder pattern as representing a certain mineral that in reality represents a mixture. This danger is particularly grave in dealing with ores whose minerals are frequently intimately intergrown. For this reason the specimens here chosen for *x*-ray analysis have been taken from polished sections by a method of micro-sampling that greatly reduces the danger of contamination. The material for this work has come chiefly from a collection of polished sections at Harvard known as the Murdoch suite. Murdoch's original assemblage, enlarged and rechecked by several later experts, has been the basis for an important part of the work done to date on the identification of ore minerals in polished section; it underlies the work of Murdoch,⁴ Talmage,⁵ and Harvey⁶ and much of the work of Farnham⁷ and Short.⁸

SAMPLING AND PREPARATION OF x -RAY MOUNTS

The use of polished sections and very small samples has required the development of slightly modified methods of securing and mounting specimens for x -ray work. It has been found possible to obtain satisfactory powder patterns with samples weighing 0.5 milligram. In sampling extremely small grains from polished sections that yield only a minimum amount of powder, it is imperative not to waste any of the sample. Sampling is accomplished by means of a micro-drill⁹ that consists of a sharp needle held in bearings at an angle of forty-five degrees to the axis of a reflecting microscope in such a position that its sharp point comes in the center of the field of view of the microscope. A small electric motor acting through a flexible cable rotates the needle. Preferably the stage of the microscope should permit raising and lowering—a type of design now becoming common. Drilling is then most easily achieved by raising the stage of the microscope and the polished specimen until the needle comes in contact with the chosen and previously centered mineral grain. The product of such drilling is a fine powder that piles up neatly at the side of the hole. The polished section and the powdered sample are carefully transferred from the reflecting microscope to a binocular microscope which affords greater working distance. Here, a drop of collodion is placed directly on the accumulated powder and when this drop is partially dry it is shaped in the form of a tiny rod in such a manner as to contain the sample concentrated in one end of the rod. This micro-drill does not work so satisfactorily on very hard or very soft minerals; and it has recently been found that a diamond chip mounted in copper in a pencil-like holder is highly satisfactory for nearly all sampling, as it yields a fine powder from either hard or soft minerals.

For preparing x -ray samples, polished sections, if they are suitably mounted in rectangular molds of bakelite or some similar medium, have a distinct advantage over ordinary mineral specimens in that any grain may be located for future reference by means of the coördinates of the mechanical stage. For the present investigation the Murdoch suite of polished sections was examined critically. Each mineral was sampled on a micro-scale and analyzed by a semi-quantitative spectrographic method. By this means it has been possible to check the authenticity of each mineral and to discard any about which there was doubt. For each specimen the coördinates were recorded for the grain from which the preliminary sample had been taken, and the final sample, for the purpose of x -ray powder patterns, was drilled from identical material on the polished surface, frequently from the very same grain.

EQUIPMENT AND MEASUREMENTS

The majority of the powder patterns were secured with x -ray equipment assembled by Dr. Berman. This consists of a gas tube provided with a series of interchangeable targets. Most of the patterns were prepared with the use of $\text{Cu-K-}\alpha$ radiation. When the sample demanded it, iron radiation was resorted to. With the gas tube, Debye powder cameras of 57.4 millimeter radius were used; these cameras yield almost a full 360° powder pattern. The sample was held on a central spindle rotated by a Telechron motor. Some of the powder patterns were taken with sealed tube equipment using $\text{Cu-K-}\alpha$ and $\text{Co-K-}\alpha$ radiation (courtesy of the International Nickel Company of Canada) and similar Debye cameras of 28.7 millimeter radius.

With both installations x -ray powder pattern spacings were measured with scales reading directly in angstroms. In each case the scales were checked by means of patterns of precipitated silver, the parameters of which are known with high accuracy. The intensity estimates recorded for each line are visual estimates of relative intensity on a scale ranging from zero to ten. The purpose of using numerical values rather than the customary designations (very strong, strong, etc.) is to establish and designate in definite order the strongest line in the pattern, the second strongest, the third strongest, etc., in order to classify, or index, the pattern on the basis of the three strongest lines. Where two lines are equally strong the one representing the larger spacing is given precedence.*

DESCRIPTION OF TABLES

In Table 1 the minerals are listed alphabetically. Each mineral is numbered and its locality stated. Since many of the specimens have been the subject of detailed work by various mineralogists, the precise number of each specimen is listed so that if desired further information concerning the actual specimen used may be secured. For this purpose the following symbols have been used:

M—Murdoch Suite

H—Harvard Museum

The radiation and filter used for each pattern is entered at the left of the page. The powder pattern data are in tabular form in three columns headed *O*, *d* and *I*. Under *O*, signifying order, the strongest, second strongest and third strongest lines of the pattern are designated by the respective figures 1, 2 and 3. Under *d* are listed the spacings in angstroms

* Photographic reproductions of all the powder patterns have been made. Copies of these, as a complete set, may be obtained, at cost, from the author.

corresponding to each line of the powder pattern. Under *I* the estimated intensity of each line is given. At the end of this table there are included a few minerals whose powder pattern is distinct but whose identity for one reason or another is in doubt.

In Table 2, column 1, the measurements in angstroms of the strongest line of each pattern have been listed in ascending order with the estimated intensity placed in brackets. The corresponding second and third strongest lines and their intensities are in columns 2 and 3, respectively. In the last column is entered the number assigned to the pattern in Table 1.

Identification of an unknown mineral is made by reference to Table 2. In column 1 a line is sought that corresponds to the strongest line of the unknown pattern. Several lines (representing as many minerals) may fall within the limits of experimental error or within the limits of the variations to be found in natural minerals. To determine which one is correct, columns 2 and 3 should next be compared, in turn, with the values for the second and the third strongest lines of the unknown pattern. In most cases a match can be found almost immediately and the complete pattern can then be compared in detail by referring to Table 1. Patterns that have one line very much stronger than all others are particularly easy to identify, because there is no doubt at all of the strongest line. However, very few patterns give trouble in selecting the three strongest lines in their proper sequence. If any two lines appear to have the same intensity, the one representing the larger spacing should be rated as the stronger. If the pattern remains unidentified, the other line is then tried as the stronger and a match may thus be found.

In comparing patterns of the same material made with Cu, Co, Fe and Mo radiation some variation in the relative intensity of lines can be seen, but in all cases thus far encountered the three strongest or index lines have remained the same, regardless of the radiation used.

Variations of the resolution of the x-ray equipment on rare occasion may cause confusion by the failure to resolve two closely spaced and moderately strong lines (for example the third and fourth in intensity), which if considered as a single line, would be ranked as the strongest line of the pattern. Schapbachite, number 129, affords an example of this kind.

The three strongest lines have been selected from the region $2\phi = 0$ to 90 degrees, where ϕ has its usual significance as in the Bragg law $n\lambda = 2d \sin \phi$. The reasons for this are:

1. Many x-ray installations are equipped with half circle or quadrant powder cameras.

2. The absorption characteristics of the sample after its preparation as a spindle for the x -ray influence the intensities of high angle diffraction lines relative to the low angle lines. It is possible, although of course not at all desirable, to prepare a spindle, of altaite for example, containing so much material that the x -ray beam can only penetrate its surface. This results in strong back reflection lines and relatively weak low angle lines and the high angle lines may easily be the strongest lines of the pattern. The effect of absorption can be adequately reduced even when dealing with unknowns by using a sample containing a minimum amount of material.

In case an unknown cannot be identified by means of the three strongest lines, two possibilities exist. First, the unknown pattern may represent not a single mineral but a mixture. Second, the pattern may not be included in the present compilation. One should proceed to test the first possibility. To do this one finds a match for the strongest line of the unknown, then looks for a match for the second or third strongest line in the region of the table including about six patterns each way from the matched strongest line. When a match for the second or third line is found, the standard pattern in Table 1 may be compared directly with the unknown and all lines corresponding with respect to spacing checked off on the unknown pattern and relative intensity noted. The remaining unchecked lines should be regarded as a separate unknown pattern to be identified in the regular manner. Superimposed lines may be recognized by greater intensities than are indicated by the standard patterns. However, if the strongest line in an unknown is the result of the superimposition of two relatively weak lines of the different components of a sample, that is really a mixture, a match may not be found and the second strongest line must then be used. Members of the staff of the Dow Chemical Company¹⁰ have found it to be practical to analyze mixtures with as many as four or five components by a method such as this.

The remarkable individuality of powder patterns which makes them so suitable for the purpose of identification has been demonstrated by the work in the Dow Chemical Company's laboratory. For instance, out of 1000 chemical substances which they investigated, it was found that among those patterns having practically identical first lines and practically identical second lines (that is to say, identical within 5 to 10 times the error of measurement), there were only eleven instances in which *two* different substances and only four instances in which *three* different substances have also the third line practically identical. And in seven of these eleven instances of confusion, the fourth line served to distinguish the patterns.

Unfortunately, natural minerals cannot be identified in quite such a clear-cut manner as pure chemical substances, even by powder patterns. Some minerals have a tendency to vary considerably in chemical composition from one occurrence to another. In minerals of the cobaltite group, for example, it is possible for any one of several elements to replace one of the elements of the mineral. When such a replacement occurs the resulting mineral is often given an independent name, but the powder pattern remains the same except for a very slight change in cell size. If some other element had been substituted, the mineral would be given still another name, and again the only difference in pattern would be a slight change in cell size. In short, members of an isomorphous mineral series give powder patterns that differ only by a small change in the spacings and little change in the relative intensities. For such cases, the powder pattern alone will not distinguish between these varieties and chemical tests must be invoked. On the other hand, certain minerals seem to show appreciable variation in unit cell size although no difference in chemical composition has been recognized.

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TABLE 1. POWDER DIFFRACTION DATA OF ORE MINERALS

The starred patterns check published data.

M—Murdoch Suite. H—Harvard Museum. B—broad line.

Cu-Ni 1. Aguilarite, $\text{Ag}_2(\text{Se}, \text{S})$. Guanajuato, Mexico. M-1A

O	d	I	O	d	I
	3.11	.3		2.09	1.0
1	2.82	4.0	3	1.99	2.0
	2.65B	.3		1.625	.3
2	2.44	3.0		1.261	.3
	2.22	1.0		1.154	.3

Cu-Ni 2. Aikinite, $\text{Cu}_2\text{S} \cdot 2\text{PbS} \cdot \text{Bi}_2\text{S}_3$. Berezov, Urals. M-2

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	4.1	3.0		2.03	1.0		1.480	.5
1	3.62	8.0		1.99	2.0		1.405	2.0
2	3.17	8.0		1.96	2.0		1.380	1.0
3	2.86	7.0		1.90	.5		1.350	.5
	2.69	4.0		1.805	.3		1.330	.5
	2.59	3.0		1.770	4.0		1.275	.5
	2.50	1.0		1.625	.3		1.265	.3
	2.36	1.0		1.590	2.0		1.155	.2
	2.27	1.0		1.522	1.0		1.120	.1
	2.17	2.0						

*Cu-Ni 3. Alabandite, MnS . Summit Co., Colorado. M-3

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.0	.3		1.995	.2		1.302	.2
	2.83	.3	2	1.845	4.0		1.165	.5
1	2.61	7.0	3	1.502	1.0		1.065	.3

4. Algodonite, Cu_6As . (See No. 163)*Cu-Ni 5. Altaite, PbTe . Burney Mine, Sonora, California. M-6

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
2	3.2	4.0	3	1.435	3.0		1.017	.5
1	2.27	5.0		1.312	2.0		.970	.5
	1.93	.5		1.136	.3		.892	.3
	1.85	1.0		1.072	1.0		.852	.2
	1.61	1.0						

Cu-Ni 6. Andorite, $\text{Ag}_2\text{S} \cdot 2\text{PbS} \cdot 3\text{Sb}_2\text{S}_3$. Oruro, Bolivia. M-7

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.7	.5		2.38	.2		1.98	.3
	3.41	.5		2.27	.5		1.88	2.0
1	3.28	4.0		2.14	.3		1.795	2.0
2	2.90	3.0		2.06	1.0		1.681	.2
3	2.75	2.0		2.01	.5		1.418	.3
							1.385	.3

*Cu-Ni 7. Antimony, Sb . Near White River, California. H-87942

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
1	3.07	6.0		1.540	1.0		1.075	.5
3	2.23	2.0		1.470	.5		1.030	.3
2	2.13	2.0		1.405	1.0		1.008	.2
	1.92	.5		1.355	1.0		.985	.2
	1.87	.5		1.251	1.0		.962	.3
	1.755	1.0		1.231	1.0		.876	.3
	1.675	.2		1.215	.3		.841	.2

Cu-Ni 8. Aramayoite, $\text{Ag}_2\text{S} \cdot (\text{Sb, Bi})_2\text{S}_3$. Chacaya, Potosi, Bolivia. M-207

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
3	3.43	4.0	1.765	1.0		1.415	1.0	
2	3.24	5.0	1.71	2.0		1.355	.3	
1	2.84	10.0	1.675	1.0		1.285	.3	
	2.06	2.0	1.625	1.0		1.240	.2	
	1.955	2.0	1.585	.5				

*Cu-Ni 9. Argentite, Ag_2S . M-9G

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.4	.5	2.08	1.0		1.51	.2	
	3.08	.5	1.99	.3		1.455	.3	
2	2.83	3.0	1.96	.3		1.41	.2	
1	2.59	4.0	1.905	.3		1.33	.2	
3	2.43	3.0	1.86	.3		1.265	.2	
	2.37	1.0	1.715	.5				
	2.21	1.0	1.575	.3				

Cu-Ni 10. Argyrodite, $4\text{Ag}_2\text{S} \cdot \text{GeS}_2$. Liza, Pio de Gallo Mine, Porco, Bolivia. M-10B

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.2	1.0	2.04	1.0		1.515	.2	
1	3.05	3.0	1.95	.3		1.480	.2	
	2.82	1.0	1.87	1.0		1.410	.2	
2	2.68	2.0	1.79	.5		1.380	.2	
3	2.45	1.0	1.70	.2		1.215	.2	
	2.18	.2	1.59	.2		1.163	.2	

*Cu-Ni 11. Arsenic, As. Broken Hill Mines, N.S.W., Australia. H-82739

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	6.50	.2	1.76	3.0		1.083	2.0	
	6.17	2.0	1.65	3.0		1.068	1.0	
	3.45	2.0	1.59	.5		1.061	1.0	
	3.14	4.0	1.53	5.0		.993	2.0	
	2.81	.5	1.433	1.0		.964	.5	
1	2.74	8.0	1.380	2.0		.952	1.0	
	2.52	2.0	1.363	1.0		.938	1.0	
	2.25	.5	1.345	1.0		.921	1.0	
	2.12	.5	1.299	.5		.897	.5	
3	2.04	5.0	1.283	3.0		.889	.5	
	1.95	1.0	1.195	4.0		.862	.2	
2	1.867	6.0	1.112	2.0		.853	1.0	
	1.837	.5	1.102	1.0		.827	1.0	

Cu-Ni 12. Arsenopyrite, FeAsS. Auburn, Maine. M-13

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
3	2.82	1.0	2.02	.5		1.54	.2	
	2.66	1.0	1.95	.3		1.342	.3	
1	2.43	3.0	2	1.82	2.0			
			1.63	.5				

13. Beegerite 6PbS · Bi₂S₃ (See page 109)Cu-Ni 14. Baumhauerite, 4PbS · 3As₂S₃. Binnenthal, Switzerland. M-15A

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.78	.5	1	2.73	2.0		2.03	.2
	3.65	.5		2.63	.5		1.95	.2
	3.40	.5	2	2.30	2.0		1.90	1.0
	2.97	.5		2.22	.2		1.78	.3
	2.89	.5	3	2.11	1.0			

Cu-Ni 15. Benjaminite, (Cu,Ag)₂S · 2PbS · 2Bi₂S₃. Outlaw Mine, Nye Co., Nevada. M-222

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.60	1.0		2.25	.5		1.72	.3
2	3.48	2.0		2.10	.5		1.64	.2
	2.96	1.0	3	2.01	2.0			
1	2.85	3.0		1.89	.5			

Cu-Ni 16. Berthierite, FeS · Sb₂S₃. M-17

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	4.30	1.0		2.035	1.0		1.495	.2
2	3.62	4.0		1.99	2.0		1.415	.5
	3.35	1.0		1.90	1.0		1.365	.5
3	3.15	4.0		1.870	2.0		1.335	.3
	3.01	1.0		1.785	1.0		1.318	.2
	2.83	4.0		1.760	1.0		1.255	.3
1	2.60	5.0		1.690	.5		1.079	1.0
	2.51	1.0		1.660	.5		1.059	1.0
	2.23	.5		1.630			1.045	.5
	2.155	1.0		1.585	1.0			

*Cu-Ni 17. Berzelianite, Cu₂Se. Skikerum, Sweden. M-320

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.51	1.0		1.41	.5		1.000	.5
2	3.20	4.0		1.34	.5		.940	2.0
	2.85	2.0		1.28	.5		.885	.5
	2.50	.5		1.20	.5		.870	.5
	2.27	1.0		1.155	.5		.835	.5
1	1.98	7.0		1.100	.3		.818	1.0
3	1.84	3.0		1.060	.5		.805	.3
	1.79	2.0		1.030	.5		.794	1.0
	1.64	2.0						

*Cu-Ni 18. Bismuth, Bi. Altenberg, near Zinnwald, Saxony, Germany. H-87945

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
1	3.21	3.0	1.304	1.0			.982	.5
	2.34	1.0	1.278	.5			.968	.5
3	2.245	2.0	1.254	.5			.943	.5
	2.015	.5	1.240	.3			.927	.5
	1.955	.5	1.180	.5			.915	.5
	1.850	1.0	1.132	2.0			.891	1.0
	1.625	1.0	1.112	1.0			.878	.3
	1.545	.5	1.088	2.0			.872	1.0
	1.480	2.0	1.069	2.0			.862	1.0
2	1.435	3.0	1.047	.5			.858	1.0
	1.378	.5	1.036	.5			.827	1.0
	1.325	2.0	1.021	1.0			.819	.5

Cu-Ni 19. Bismuthinite, Bi₂S₃. Persberg, Sweden. M-20

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	5.55	1.0	1.870	1.0			1.242	.5
	4.95	1.0	1.840	1.0			1.184	2.0
	3.92	2.0	1.725	5.0			1.160	.5
1	3.50	9.0	1.690	1.0			1.138	2.0
	3.22	1.0	1.670	1.0			1.116	.5
2	3.08	6.0	1.595	.2			1.096	.3
	2.79	4.0	1.550	3.0			1.082	.3
	2.69	1.0	1.521	.5			1.053	2.0
	2.61	1.0	1.475	2.0			1.028	1.0
	2.495	3.0	1.430	2.0			1.017	1.0
	2.425	1.0	1.390	1.0			.990	.5
	2.28	1.0	1.375	1.0			.974	.2
	2.23	3.0	1.347	2.0			.965	2.0
	2.11	1.0	1.315	1.0			.897	2.0
	2.06	.5	1.302	2.0			.881	.3
	1.98	1.0	1.289	.5			.865	.2
3	1.935	5.0	1.275	.5			.846	.3

*Cu-Ni 20. Bornite, Cu₅FeS₄. Magma, Arizona.

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
2	3.31	2.0	1.65	1.0			1.265	.3
3	3.15	2.0	1.58	.1			1.117	2.0
	2.82	.5	1.535	.2			.967	.5
	2.74	2.0	1.47	.1			.925	.3
	2.51	2.0	1.425	.5				
	2.12	.3	1.372	.5				
1	1.94	8.0						

*Cu-Ni 21. Boulangerite, $5\text{PbS} \cdot 2\text{Sb}_2\text{S}_3$, M-22

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
2	3.68	2.0	1	2.80	3.0		1.77	.5
	3.21	.2	3	2.00	1.0			
	3.00	.5		1.93	.2			
				1.86	1.0			

*Cu-Ni 22. Bournonite, $\text{Cu}_2\text{S} \cdot 2\text{PbS} \cdot \text{Sb}_2\text{S}_3$, Cornwall, England. H-82462

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
2	3.90	1.0		2.59	1.0	3	1.765	1.0
	3.69	.5		2.37	.3		1.665	.3
	3.26	.5		2.24	.2		1.63	.3
	2.97	.5		2.17	.2		1.59	.2
	2.90	.2		2.10	.2		1.56	.2
	2.82	.2		1.99	.3		1.425	.3
1	2.74	5.0		1.95	1.0		1.39	.3
	2.68	.5		1.85	1.0		1.26	.3

Cu— 23. Bravoite, $(\text{Fe}, \text{Ni})\text{S}_2$, Minas Ragra, Peru. M-209

Note similarity to pyrite No. 117

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.21	.5		1.682	.2		1.178	.2
	3.08	.5	2	1.675	3.0		1.135	.2
1	2.77	4.0		1.61	.3		1.072	.5
3	2.49	2.0		1.545	.3		1.035	.3
	2.27	1.0		1.488	.5		.984	.2
	2.18	.2		1.275	.3		.929	.2
	2.04	.2		1.246	.3		.904	.2
	1.97	1.0		1.215	.2		.880	.2
	1.86	.3						

Fe— 24. Braunite, $3\text{Mn}_2\text{O}_3 \cdot \text{MnSiO}_3$, Vizagapatan Dist., Madras, India. H-83692

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	4.65	.3		1.822	.3		1.365	.5
	3.455	1.0		1.80	.3		1.35	1.0
	3.33	.3		1.76	.5		1.265	.5
	2.955	.5	2	1.65	6.0		1.174	.3
1	2.69	9.0		1.533	1.0		1.165	.3
	2.34	2.0		1.495	1.0		1.145	.2
	2.138	2.0		1.46	1.0		1.076	2.0
	1.865	.5	3	1.415	3.0		1.05	1.0

Cu—25. Breithauptite, NiSb. Andreasberg, Harz, Germany. M-24

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.12	.5		1.62	1.0		1.150	.3
1	2.85	5.0		1.56	.3		1.135	.2
	2.56	.2		1.525	1.0		1.075	.3
	2.26	.3		1.415	1.0		1.028	.3
	2.17	.3		1.280	.2		.981	.2
2	2.05	2.0		1.248	.5		.932	.2
3	1.97	2.0		1.210	.2			

Cu-Ni 26. Calaverite, (Au, Ag)Te₂. Cripple Creek, Colorado. M-26A

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
1	2.99	5.0		1.22	.5		.882	.3
	2.20	.5		1.20	1.0		.862	.3
2	2.09	4.0		1.09	.3		.847	.5
	1.93	.5		1.055	.3		.830	.5
3	1.77	1.0		1.030	.5		.820	.5
	1.68	1.0		1.005	.5		.812	.5
	1.51	1.0		.975	1.0		.791	.5
	1.37	.5		.952	.5		.789	.5
	1.34	1.0		.936	.3		.785	1.0
	1.31	1.0		.928	.2		.779	1.0
	1.26	1.0		.890	1.0			

Cu-Ni 27. Cannizarite (=galenobismutite), PbS·2Bi₂S₃. From fumeroles, Lipari Islds. Italy. H-89262

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
1	3.80	3.0		1.79	1.0		1.265	.2
	3.51	1.0		1.735	.5		1.228	.3
	3.35	1.0		1.68	.5		1.205	.3
2	3.00	3.0		1.62	.3		1.168	.3
	2.87	2.0		1.58	.2		1.145	.3
	2.78	.3		1.482	.2		1.130	.2
	2.68	2.0		1.435	.2		1.075	.2
	2.54	.2		1.385	.2		1.050	.2
	2.37	.2		1.355	.2		1.012	.2
	2.22	1.0		1.320	.2		.995	.2
3	2.03	3.0		1.295	.3		.961	.2
	1.90	.5						

Cu—28. Carrollite, (Co, Cu)₃S₄. Finksburg, Maryland. M-27

Note pattern identity with violarite, linnæite, polydymite.

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.35	1.0		1.82	4.0		1.18	.3
	3.15	.5	2	1.67	5.0		1.06	.3
1	2.85	6.0		1.43	.3		.988	.5
3	2.47	4.0		1.36	.3		.965	1.0
	2.03	.3		1.23	.3		.915	1.0
	1.92	.5						

*Cu-Ni 29. Cassiterite, SnO_2 . Llallagua, Bolivia.

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
1	3.32	6.0	1.405	2.0		.945	3.0	
2	2.62	6.0	1.315	1.0		.926	1.0	
	2.35	2.0	1.209	2.0		.912	1.0	
	2.28	.5	1.179	.5		.905	2.0	
	2.11	.3	1.149	1.0		.879	3.0	
3	1.75	6.0	1.111	1.0		.846	3.0	
	1.665	2.0	1.086	2.0		.836	1.0	
	1.58	1.0	1.075	2.0		.824	2.0	
	1.49	2.0	1.055	1.0		.811	.5	
	1.43	2.0	1.031	1.0		.805	2.0	

*Cu-Ni 30. Cerargyrite, AgCl . Southeast California. H-82732

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
3	3.20	.5	1.61	.5		.987	.2	
1	{2.80	2.0}	1.395	.2		.930	.2	
	{2.75	2.0}	1.274	.2		.883	.2	
2	1.97	1.0	1.245	.5		.843	.2	
	1.67	.3						

*Cu-Ni 31. Chalcocite, Cu_2S . Magma, Arizona.

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.37	1.0	2.06	.5		1.345	.3	
	3.18	.5	1	1.95	8.0	1.275	1.0	
	3.02	.5	2	1.865	8.0	1.125	.3	
	2.85B	1.0		1.685	2.0	1.068	.5	
	2.67B	.5		1.638	1.0	.971	.2	
3	2.38	6.0		1.505	.5	.936	.2	

*Cu-Ni 32. Chalcopyrite, CuFeS_2 . Franklin, New Jersey. M-191A

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
1	3.03	7.0	3	1.59	1.0	1.205	.5	
	2.62	.2		1.52	.2	1.075	.5	
2	1.86	4.0		1.32	.5			

Cu-Ni 33. Chalcostibite, $\text{Cu}_2\text{S} \cdot \text{Sb}_2\text{S}_3$. R \bar{a} r-el-Anz, Morocco. H-88659

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.67	.5		1.83	3.0		1.262	.5
1	3.13	8.0	3	1.76	4.0		1.202	.3
2	2.99	8.0		1.69	.5		1.145	.3
	2.80	.2		1.61B	2.0		1.084	.2
	2.55	.2		1.550	1.0		1.068	.2
	2.31	3.0		1.440	1.0		1.006	.2
	2.24	.5		1.345	.5		.981	.2
	2.12	1.0		1.310	.5		.950	.2
	1.90	1.0		1.289	1.0			

Cu—34. Chloanthite-smaltite, (Ni, Co)As₂. Schneeberg, Saxony, Germany. M-36

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	6.0	1.0		1.77	1.0		1.20	1.0
	4.2	2.0		1.69	2.0		1.17	1.0
	3.4	1.0		1.63	3.0		1.15	1.0
	2.9	2.0		1.43	2.0		1.13	1.0
1	2.64	9.0		1.38	1.0		1.09	2.0
3	2.22	3.0		1.31	.5		1.05	1.0
	2.07	.5		1.25	.3		1.005	1.0
	1.95	1.0		1.23	2.0		.990	.5
2	1.87	4.0						

*Cu-Ni 35. Chromite, FeO·Cr₂O₃. M-37B

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
3	3.10	.5	1	2.02	3.0		1.26	.2
2	2.82	1.0		1.62	.2		1.17	.2
	2.21	.3						

*Cu-Ni 36. Cinnabar, HgS. Almaden, Spain. H-88522

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
1	3.34	9.0		1.360	.5		1.014	.3
	3.16	1.0		1.345	.5		.992	.5
2	2.85	9.0		1.305			.975	.5
	2.36	.5		1.268	1.0		.960B	.5
	2.07	3.0		1.258	1.0		.950B	.5
	2.02	1.0		1.248	.5		.941	.5
	1.980	3.0		1.179	.5		.918	1.0
	1.900	.3		1.161	.3		.910	.5
	1.765	2.0		1.125	.3		.898B	.3
	1.735	3.0		1.120	.2		.882	.5
3	1.680	4.0		1.105	1.0		.865	.5
	1.581	1.0		1.083	.5		.840	.5
	1.560	1.0		1.069	.5		.833	.2
	1.435	2.0		1.031	1.0		.820	.2
	1.401	.5						

*Cu-Ni 37. Clausthalite, PbSe. Prov. of Mendoza, Argentina. M-39B

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.53	3.0		1.530	2.0		1.035	.2
1	3.06	9.0		1.405	.5		1.020	1.0
	2.86	.3	3	1.370	4.0		.968	1.0
2	2.165	7.0		1.250	3.0		.923	.5
	1.850	2.0		1.180	.5		.849	.3
	1.770	3.0		1.083	.5		.818	.3

*Cu-Ni 38. Cobaltite, CoAsS. Cobalt, Ontario. M-40

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.12	.5		2.21	.5		1.622	.3
1	2.81	4.0	2	{ 2.03	2.0 }		1.545	.2
3	2.49	2.0		{ 2.00	2.0 }		1.490	1.0
	2.27	1.0		1.688	1.0		1.405	.3

*Cu-Ni 39. Coloradoite, HgTe. Vulcan Mine, Gunnison Co., Colorado. M-136

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.23	.2		1.485	3.0		1.023	1.0
	2.82	.2	3	1.320	4.0		.985	.3
	2.52	.3		1.245	3.0		.905	.3
1	2.28	10.0		1.142	1.0		.865	.3
2	1.955	7.0		1.093			.842	.2
	1.620	2.0						

Co— 40. Columbite-tantalite, (Fe, Mn)(Cb, Ta)₂O₆. M-230

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.65	2.0		2.08	1.0		1.38	1.0
1	3.00	10.0		1.78	1.0		1.19	.3
	2.53	2.0	2	1.72	4.0		1.100	1.0
	2.39	1.0		1.54	2.0		1.075	1.0
	2.25	1.0	3	1.45	3.0		1.032	.2

*Cu-Ni 41. Colusite, (Cu, Fe, Mo, Sn)₄(S, As, Te)₃₋₄. Butte, Montana.

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
1	3.07	7.0		1.327	1.0		.982	.2
	2.82	.5		1.240	2.0		.939	.3
	2.66	.5		1.085	3.0		.898	.5
2	1.88	5.0		1.022	1.0		.841	.5
3	1.601	3.0						

*Cu-Ni 42. Copper, Cu.

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
1	2.08	8.0		1.088	3.0		.8285	.5
2	1.81	4.0		1.043	1.0		.808	.5
3	1.275	3.0		.903	.3			

Cu— 43. Corynite, Ni(As, Sb)S. Olsa, Carinthia, Austria. M-210

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	2.85	4.0		1.40	.5		.921	1.0
1	2.55	6.0		1.24	1.0		.868	.5
3	2.33	4.0		1.21	.5		.858	.3
	2.02	.5		1.16	.3		.848	.5
	1.91	.2		1.11	.3		.839	.5
2	1.71	5.0		1.09	2.0		.820	.3
	1.65	.5		1.06	1.0		.790	.3
	1.57	2.0		1.035	.5		.782	.3
	1.51	3.0		1.002	2.0			

*Cu-Ni 44. Cosalite, $2\text{PbS} \cdot \text{Bi}_2\text{S}_3$, M-43A

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.75	.5	1	2.95	4.0	3	2.02	2.0
	3.52	.5		2.80	1.0		1.91	.5
2	3.40	2.0		2.27	.5		1.80	.5
	3.30	.5		2.14	1.0		1.75	.5
	3.06							

*Cu-Ni 45. Covellite, CuS . Butte, Montana.

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.22	2.0		2.31	.5		1.352	.5
3	3.02	7.0	1	1.90	9.0		1.280	.5
2	2.82	8.0		1.735	4.0		1.098	.5
	2.72	6.0		1.560	6.0		1.061	.5

*Fe— 46. Cubanite, $\text{CuS} \cdot 2\text{FeS}$. Sudbury, Ontario.

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.50	2.0		2.255	.5	3	1.75	3.0
1	3.23	5.0		2.21	.2		1.70	.3
	3.115	.5		2.06	.5		1.61	.5
	3.00	1.0		1.99	.3		1.50	.3
	2.79	1.0		1.935	.3		1.295	.5
	2.50	.5	2	1.875	4.0		1.165	.5
	2.375	.5					1.075	.2
							1.050	.2

*Cu-Ni 47. Cuprite, Cu_2O . Cuba. M-47A

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.00	.5	2	2.13	1.0	3	1.51	.5
1	2.46	5.0					1.285	.3

Cu-Ni 48. Cuprodesclowitzite, $\text{Pb}_2(\text{Zn}, \text{Cu})_2\text{V}_2\text{O}_9 \cdot \text{H}_2\text{O}$. Skattuck Mine, Bisbee, Arizona. M-48

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	5.0	.5		2.46	.2		1.538	.3
	4.55	.3		2.36	.2		1.492	.3
	4.20	.3		2.28	.5		1.450	.2
	3.54	.5		2.08	.5		1.395	.3
1	3.22	4.0		1.87	.3		1.335	.2
	2.97	.3		1.77	1.0		1.250	.3
	2.86	1.0		1.72	.2		1.112	.2
2	2.67	2.0	3	1.64	2.0		1.075	.2
	2.60	.5						

Cu-Ni 49. Cyndrite, $6\text{PbS} \cdot \text{Sb}_2\text{S}_3 \cdot 6\text{SnS}_2$. Mina Santa Cruz, Poopo, Bolivia. M-49

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.45	.2	2	2.03	1.0		1.455	.3
	3.15	.2	3	1.81	1.0		1.290	.2
1	2.89	4.0						

Cu-Ni 50. Daubreelite, $\text{FeS} \cdot \text{Cr}_2\text{S}_3$. Alliers, France. H-82055

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.52	1.0	2	1.77	6.0		1.152	.3
1	3.02	6.0		1.52	.3		1.116	.3
3	2.50	3.0		1.44	.3		1.046	.2
	2.04	.5		1.30	.5		1.020	1.0
	1.925	3.0		1.25	.5		.965	.3

*Cu-Ni 51. Delafossite, $\text{Cu}_2\text{O} \cdot \text{Fe}_2\text{O}_3$. Bisbee, Arizona. M-50

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
2	2.84	1.0		1.66	1.0		1.340	1.0
1	2.51	5.0		1.515	1.0		1.295	.5
3	2.23	1.0		1.435	.5		1.080	.2

Cu-Ni 52. Diaphorite, $3\text{Ag}_2\text{S} \cdot 4\text{PbS} \cdot 3\text{Sb}_2\text{S}_3$. Příbram, Bohemia. H-80251

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
1	3.28	5.0		1.84	.3		1.320	.3
	2.92	1.0		1.76	1.0		1.305	.3
2	2.80	4.0		1.705	1.0		1.286	.3
	2.23	.2		1.65	.5		1.271	.3
	2.08	.2		1.585	.3		1.254	.3
3	2.04	2.0		1.520	.2		1.154	.3
	2.01	.3		1.470	.2		1.130	.2
	1.99	.3		1.410	.5		1.090	.2

Co-Fe 53. Dufrenoyite, $2\text{PbS} \cdot \text{As}_2\text{S}_3$. Binnenthal, Switzerland. M-53

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.36	.5		2.20	.5		1.53	.5
	3.20	.5	3	2.09	2.0		1.45	.2
1	3.01	4.0		1.91	.5		1.42	.2
2	2.84	3.0		1.86	.5		1.22	.2
	2.32	1.0						

Cu-Ni 54. Dyscrasite, As_3Sb . Andreasberg, Germany. M-24D

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
3	2.55	1.0	1.76	.2		1.35	.2	
2	2.39	2.0	1.475	.2		1.265	.2	
1	2.26	4.0						

*Cu-Ni 55. Emplectite, $\text{Cu}_2\text{S} \cdot \text{Bi}_2\text{S}_3$. Johanngeorgenstadt, Saxony, Germany. H-82378

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	4.7	1.0	1.755	.5		1.100	.3	
2	3.20	7.0	1.655	2.0		1.090	.3	
1	{ 3.10 } 3.02	8.0	1.560	1.0		1.055	.3	
			1.475	.3		1.040	.3	
	2.81	.3	1.450	1.0		1.015	.3	
	2.72	.2	1.365	.5		1.000	.5	
3	2.34	3.0	1.320	1.0		.971	.3	
	2.24	.5	1.260	.3		.948	.3	
	2.16	3.0	1.225	1.0		.928	.3	
	1.96	1.0	1.208	1.0		.918	.3	
	1.86	2.0	1.190	1.0		.908	.3	
	1.80	2.0	1.168	2.0		.899	.3	
	1.78	.5	1.112	.5		.871	.3	

*Cu-Ni 56. Enargite, $\text{Cu}_2\text{S} \cdot 4\text{CuS} \cdot \text{As}_2\text{S}_3$. Tintic, Utah. H-82656

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
1	3.21	8.0	1.425	.5		1.046	3.0	
	3.08	6.0	1.266	2.0		1.014	.5	
2	2.85	8.0	1.215	1.0		.978	.5	
	2.22	3.0	1.195	1.0		.928	.5	
3	1.86	7.0	1.150	1.0		.899	.5	
	1.73	5.0	1.130	.5		.8605	.5	
	1.59	4.0	1.072	.5		.818	.5	
	1.555	1.0						

Cu-Ni 57. Famatinite (luzonite), $\text{Cu}_2\text{S} \cdot 4\text{CuS} \cdot \text{Sb}_2\text{S}_3$. Sierro de Famatina, Argentina. H-80792

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.23	.5	1.73	.2		1.079	1.0	
1	3.06	10.0	1.59	4.0		1.018	.5	
	2.85	.3	1.53	.2		.931	.3	
	2.66	.5	1.327	.3		.895	.3	
2	1.87	8.0	1.212	1.0		.836	.2	

Fe— 58. Ferberite, FeWO_4 . Nederland, California. M-211

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	5.69	.5		1.935	.3		1.316	.5
	5.22	.5		1.872	1.0		1.295	.3
2	4.71	4.0		1.815	.5		1.272	.3
	3.76	2.0		1.760	1.0		1.231	.3
	3.64	2.0	3	1.71	4.0		1.225	.3
	3.24	3.0		1.658	.3		1.212	.2
1	2.94	8.0		1.625	.2		1.201	.2
	2.84	.5		1.584	1.0		1.185	.5
	2.735	1.0		1.510	3.0		1.175	.3
	2.620	.5		1.462	.5		1.132	.3
	2.490	3.0		1.450	1.0		1.116	.3
	2.370	1.0		1.433	2.0		1.098	.2
	2.195	3.0		1.370	1.0		1.089	.3
	2.060	1.0		1.325	.5		1.080	.3
	2.00	1.0					1.066	.3
							1.041	.3
							1.025	.2

Cu-Ni 59. Franckeite, $5 \text{ PbS} \cdot \text{Sb}_2\text{S}_3 \cdot 2 \text{ SnS}_2$. Poopo, Bolivia. M-61A

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
2	3.43	3.0		2.22	.5		1.441	.3
	3.15	.3	3	2.06	2.0		1.300	.1
1	2.88	5.0		1.82	1.0			

Cu-Ni 60. Franklinitite, $(\text{Fe}, \text{Zn}, \text{Mn})\text{O} \cdot (\text{Fe}, \text{Mn})_2\text{O}_3$. Franklin, New Jersey. M-12

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.00	1.0		1.28	.5		.972	1.0
1	2.55	7.0		1.13	.5		.881	
	2.12	1.0		1.10	1.0		.860	
	1.70	.5		1.05	1.0		.826	
3	1.62	2.0		.995			.815	
2	1.49	4.0						

Cu-Ni 61. Freieslebenite, $2\text{Ag}_2\text{S} \cdot 3\text{PbS} \cdot 3\text{Sb}_2\text{S}_3$. Verdad de los Aristas Mine, Guadalajara near Hiedelaencina, Spain. H-93145

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
1	3.45	5.0		2.01	2.0		1.481	.3
	3.23	1.0		1.88	1.0		1.410	.3
	3.11	1.0		1.78	1.0		1.385	.3
3	2.96	2.0		1.725	1.0		1.365	.3
2	2.82	5.0		1.68	1.0		1.330	.3
	2.23	.3		1.625	.3		1.255	.2
	2.13	1.0		1.560	.3		1.215	.2
	2.07	2.0		1.515	.2			

Cu-Ni 62. Fuloppite, $2\text{PbS} \cdot 3\text{Sb}_2\text{S}_3$. Nagybánya, Rumania. M-212A

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
2	3.82	.5	2.74	.3		2.00	.3	
	3.61	.3	2.47	.3		1.89	.3	
3	3.38	.5	2.23	.5		1.75	.2	
1	3.23	1.0	2.14	.3		1.69	.2	
	2.93	.5						

*Cu-Ni 63. Galena, PbS. Joplin, Missouri.

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.42	3.0	1.325	5.0		.938	3.0	
1	2.96	6.0	1.220	4.0		.905	.5	
2	2.08	5.0	1.140	3.0		.895	3.0	
3	1.785	5.0	1.049	1.0		.856	.5	
	1.710	3.0	1.004	2.0		.831	3.0	
	1.480	3.0	.989	3.0		.823	3.0	
	1.360	2.0						

Cu-Ni 64. Geocronite, $5\text{PbS} \cdot \text{Sb}_2\text{S}_3$. Sala, Sweden. M-66

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.69	.5	1 2.23	5.0		1.480	.2	
	3.50	1.0	2.115	2.0		1.450	.2	
	3.37	1.0	2.09	.5		1.410	.2	
3	3.19	1.0	2.04	.5		1.325	.2	
	3.04	1.0	1.945	1.0		1.299	.3	
	2.97	.5	2 1.830	3.0		1.255	.2	
	2.88	1.0	1.765	2.0		1.162	.3	
	2.79	.5	1.730	.3		1.117	.2	
	2.71	.5						

*Cu-Ni 65. Germanite, Cu_2GeS_7 . Tsumeb, S.W. Africa. H-91131

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
1	3.07	8.0	3 1.60	2.0		1.080	.5	
	2.66	.5	1.325	.3		1.017	.2	
2	1.875	4.0	1.215	.3		.934	.2	

*Cu— 66. Gersdorffite, NiAsS . Sudbury, Ontario.

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	2.83	4.0	1.518	2.0		1.038	.5	
1	2.53	6.0	1.270	.3		1.000	2.0	
3	2.31	5.0	1.240	1.0		.923	2.0	
	2.01	1.0	1.208	.5		.866	1.0	
	1.90	.5	1.148	.2		.847	.3	
2	1.715	6.0	1.093	2.0		.834	.3	
	1.55	1.0	1.055	1.0				

Co— 67. Glaucodot, (Co, Fe)AsS. Hakansba, Sweden. U. S. National Museum No. 93558

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.72	1.0		1.94	.5		1.53	.5
	2.96	.3	3	1.82	4.0		1.415	.3
	2.84	1.0		1.75	1.0		1.380	.5
2	2.72	5.0		1.635	3.0		1.345	1.0
1	2.45	8.0		1.59	1.0		1.270	.3
	2.18	.5		1.555	.5		1.210	2.0
	2.02	.3						

Co— 68. Goethite, FeO(OH). Marquette, Michigan. M-213

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
1	4.17	9.0	3	1.73	3.0		1.195	.3
	3.36	.5		1.58	.5		1.140	.5
	2.69	2.0		1.565	1.0		1.115	.3
2	2.46	4.0		1.51	1.0		1.050	.3
	2.21	2.0		1.46	1.0		1.020	.3
	1.915	.5		1.31	.5		1.008	.3
	1.80	1.0						

*Cu-Ni 69. Gold, Au. North Carolina. H-90583

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
1	2.36	9.0		1.175	1.0		.910	2.0
2	2.04	6.0		1.017	.3		.830	3.0
	1.44	4.0		.933	2.0		.784	3.0
3	1.23	5.0						

Cu-Ni. 70. Gratonite, Pb₂₇As₁₂S₄₅. Cerro de Pasco, Peru. Type material

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
1	3.80	5.0		1.60	.3		1.065	.5
2	3.47	5.0		1.50	.5		.890	1.0
3	2.94	3.0		1.43	1.0		.875	2.0
	2.74	3.0		1.36	1.0		.844	.5
	2.22	2.0		1.20	.7		.832	1.0
	2.07	2.0		1.16	.5		.817	.5
	1.93	1.0		1.095	1.0		.805	
	1.75	1.0						

*Cu-Ni 71. Graphite, C.

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
1	3.40	10.0		1.23	2.0		.990	1.0
2	2.06	3.0		1.155	2.0		.838	.3
3	1.68	2.0		1.120	.3		.827	1.0
	1.54	.5		1.050	.3		.799	2.0

Cu-Ni 72. Greenockite, CdS. Bishoptown, Scotland. M-235

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.55	2.0		1.57	.3		1.122	.5
	3.32	1.0		1.395	1.0		1.072	.5
1	3.12	4.0		1.322	1.0		1.032	.3
	2.42	1.0		1.30	.3		.982	.3
2	2.06	3.0		1.255	1.0		.952	.3
3	1.89	3.0		1.190	.5		.906	.3
	1.75	2.0		1.155	1.0		.815	.2

Cu-Ni 73. Grunlingite, Bi₄S₃Te, Bandy Grill, Cumberland, England. M-231
Orueteite yields an identical pattern.

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	4.40	1.0	3	2.25	2.0		1.542	.5
	3.65	1.0	2	2.13	3.0		1.410	.5
	3.35	.5		1.98	.3		1.355	1.0
1	3.10	9.0		1.92	.3		1.305	.3
	2.80	.3		1.75	1.0		1.250	.3
	2.58	.5						

Cu-Ni 74. Guanajuatite, Bi₂(Se, S)₃. Guanajuato, Mexico. M-70

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	5.85	.5		2.57	3.0		1.585	2.0
	5.15	1.0		2.50	.5		1.518	1.0
	4.05	1.0		2.29	3.0		1.460	.5
1	3.61	9.0		2.15	1.0		1.382	.5
2	3.16	8.0		1.98	4.0		1.330	.5
	3.01	.3		1.89	1.0		1.278	.3
3	2.86	4.0		1.765	2.0		1.215	.3
	2.76	1.0		1.702	.3		1.160	.3
	2.67	1.0						

Cu-Ni 75. Guitermanite, 3PbS·As₂S₃. Zuni mine, Silverton, Colorado. M-72

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	4.80	.5	2	2.22	2.0		1.435	.3
	4.4	.5		2.11	1.0		1.395	.3
	4.2	.5		2.02B	.5		1.355	.3
	3.68	.5		1.93	1.0		1.335	.3
	3.52	1.5		1.87	.2		1.318	.3
	3.36	1.5	3	1.82	2.0		1.292	.3
1	3.18	3.0		1.75	1.0		1.266	.3
	3.04	1.0		1.72	.3		1.248	.3
	2.88	1.0		1.68	.3		1.232	.3
	2.78	.5		1.60	.2		1.207	.3
	2.70	.5		1.585	.2		1.182	.3
	2.57	.2		1.482	.2		1.160	.3
	2.37	.2		1.460	.3		1.115	.2

*Fe— 76. Hauerite, MnS_2 . Raddusa, Sicily. M-75

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
1	3.035	3.0	2.15	1.0		1.625	1.0	
2	2.715	1.0	1.832	1.0		1.172	1.0	
3	2.49	1.0						

Fe— 77. Hausmannite, Mn_3O_4 . Harz Mts., Germany. M-190

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.08	2.0	1.700	.5		1.275	.3	
	2.865	1.0	1.640	.3		1.225	.3	
3	2.76	3.0	1.575	.5		1.193	.3	
2	2.490	4.0	1.545	2.0		1.169	.2	
	2.36	1.0	1.440	1.0		1.120	.2	
1	2.030	5.0	1.348	.5		1.080	.2	
	1.795	1.0						

*Co— 78. Hematite. Fe_2O_3 .

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	4.06	.3	1.58	.5		1.135	.3	
	3.66	1.0	1.485	1.0		1.100	.5	
1	2.69	7.0	1.44	2.0		1.055	.5	
3	2.51	4.0	1.30	.5		1.030	.3	
	2.18	2.0	1.255	.3		.987	.3	
	1.835	3.0	1.182	.3		.959	.5	
2	1.68	5.0	1.160	.3		.952	.3	

Cu-Ni 79. Hessite, Ag_2Te . Calaveras Co., California. M-77B

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.35	.5	2.180	1.0		1.585	.5	
	3.15	1.0	2.130	4.0		1.440	1.0	
	2.975	4.0	2.020	1.0		1.392	3.0	
1	2.870	6.0	1.930	.5		1.342	.3	
	2.690	.5	1.850	.3		1.302	.5	
	2.450	.3	1.810	.3		1.260	.3	
2	2.300	6.0	1.775	.5		1.250	.3	
3	2.240	5.0	1.690	.5				

Fe— 80. Hübnerite, MnWO_4 . Silverton, Colorado. M-214

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	5.72	1.0	2.49	3.0		1.715	1.0	
	5.28	.5	2.41	1.0		1.600	.2	
2	4.83	6.0	2.22	1.0		1.525	1.0	
	4.11	.5	2.05	.3		1.470	.5	
3	3.77	5.0	2.02	.3		1.380	1.0	
	3.28	1.0	1.885	.5		1.325	.3	
1	2.965	8.0	1.845	.5		1.225	.2	
	2.87	.5	1.785	1.0		1.198	.3	
	2.74	.5	1.745	1.0				

Fe-Mn 81. Ilmenite, $\text{FeO} \cdot \text{TiO}_2$, Egersund, Norway. M-81C

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
1	2.72	2.0	1.86	.5		1.498	.3	
2	2.53	2.0	1.717	1.0		1.458	.3	
	2.225	1.0	1.622	.2		1.326	.2	
3	2.025	2.0						

Cu-Ni 82. Jamesonite, $4\text{PbS} \cdot \text{FeS} \cdot 3\text{Sb}_2\text{S}_3$, Cornwall, England. M-83

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
1	3.40	3.0	2.23	1.0		1.75	.2	
	3.10B	1.0	2.04	1.0		1.71	.2	
2	2.81	2.0	2.01	1.0		1.45	.3	
3	2.72	2.0	1.90	.5		1.41	.2	
	2.28	1.0	1.825	1.0				

Cu-Ni 83. Jordanite, $4\text{PbS} \cdot \text{As}_2\text{S}_3$, Silesia. M-84

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.49	1.0	2.75	.5		2.01	.5	
	3.31	1.0	2.48	.3		1.93	.5	
	3.15	1.0	2.36	.3		3	1.815	2.0
	3.01	1.0	1	2.22	3.0	1.745	1.0	
	2.87	1.0	2	2.10	2.0			

Cu— 84. Kallilite, $\text{Ni}(\text{Sb}, \text{Bi})\text{S}$, Westphalia. M-86

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	4.15	.3		1.87	.2		1.255	.3
	3.41	.2	3	1.78	1.0		1.155	.2
	2.93	.5		1.70	.3		1.130	.2
1	2.62	5.0		1.63	1.0		1.090	.3
2	2.40	2.0		1.575	1.0		1.075	.3
	2.32	.3		1.470	.2		1.040	.3
	2.08	.3		1.390	.2		.955	.2
	1.98	.2		1.285	.5		.876	.2

Cu-Ni 85. Kermesite. $\text{Sb}_2\text{S}_2\text{O}$. M-87

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	5.15	1.0		2.21	.2		1.575	.5
	4.35	1.0		2.18	.2		1.525	.3
	4.09	1.0		2.09	.2		1.490	.3
	3.82	.5		2.03	2.0		1.445	.3
	3.67	.3		1.99	.3		1.390	.2
	3.30	.5		1.91	.5		1.350	.5
1	3.14	5.0		1.820	.3		1.310	.3
2	2.92	4.0		1.785	1.0		1.295	.2
3	2.70	3.0		1.74	.2		1.205	.2
	2.50	2.0		1.69	.3		1.120	.2
	2.27	1.0		1.63	1.0		1.100	.2

Cu Ni 86. Klaprotholite, $3\text{Cu}_2\text{S} \cdot 2\text{Bi}_2\text{S}_3$. Schapbachthal, Baden, Germany. M-89A

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	5.7	.5		2.39	1.0		1.500	.3
	5.1	.5		2.31	.3		1.455	.3
1	4.57	4.0		2.18	.5		1.410	.3
	4.10	.2		2.10	.3		1.385	.3
	3.81	2.0		2.04	.5		1.315	.2
	3.60	.5		1.99	2.0		1.300	.3
	3.35	.5		1.895	1.0		1.260	.3
	3.18	1.0		1.82	2.0		1.232	.3
3	3.07	3.0		1.76	1.0		1.205	.3
	2.95	1.0		1.73	.5		1.160	.3
2	2.85	3.5		1.68	2.0		1.125	.2
	2.65	2.0		1.60	.5		1.078	.2
	2.57	1.0		1.550	.3		1.065	.2

Cu-Ni 87. Klockmannite, CuSe. Harz, Germany.

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.35	1.0		1.84	4.0		1.158	.5
1	3.25	8.0		1.64	2.0		1.102	.3
3	2.90	7.0		1.42	.3		.995	.5
	2.20	.3		1.34	.5		.945	.2
2	2.00	8.0		1.28	.3		.887	.2

Cu-Ni 88. Kobellite, $2\text{PbS} \cdot (\text{Bi}, \text{Sb})_2\text{S}_3$. Hvena, Sweden. M-90A

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	4.25	.3	1	2.86	3.0		1.94	.2
	4.00	.5		2.72	2.0		1.81	.3
	3.78	.5		2.60	.3		1.74	.5
2	3.55	2.0		2.31	.3		1.71	.2
3	3.38	2.0		2.25	.3		1.46	.2
	3.27	1.0		2.13	1.0		1.43	.2
	3.14	.5		2.02	1.0		1.39	.2
	2.98	.5						

Cu-Ni 89. Krennerite, $(\text{Ag}, \text{Au})\text{Te}_2$. Cripple Creek, Colorado. M-91

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
1	3.05	8.0		1.98	.3		1.350	.5
3	2.95	3.0		1.785	1.0		1.322	.5
	2.24	1.0		1.699	1.0		1.271	.3
2	2.12	5.0		1.522	1.0		1.205	.5
	2.07	.5		1.475	.5			

*Cu-Ni 90. Lead, Pb. Långban, Sweden.

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
2	2.84	8.0	1.233	1.0		.9515	6.0	
	2.445	6.0	1.133	6.0		.875	1.0	
3	1.740	7.0	1.105	6.0		.8365	6.0	
1	1.485	9.0	1.009	6.0		.8250	5.0	
	1.423	4.0						

Cu-Ni 91. Linnaeite, Co_3S_4 . Siegen, Westphalia. M-96A

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.35	1.0	1.44	.5		.985	.5	
1	2.82	6.0	1.37	.5		.960	2.0	
3	2.38	2.0	1.23	1.0		.908	1.0	
	1.91	.3	1.17	1.0		.831	1.0	
	1.82	2.0	1.085	.5		.797	.5	
2	1.68	5.0	1.055	.5		.784	1.0	

Cu-Ni 92. Livingstonite, $\text{HgS} \cdot 2\text{Sb}_2\text{S}_3$. Beresow, near Ekaterinberg, Russia. M-97A

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	5.10	1.0	2.03	.3		1.50	1.0	
2	3.75	3.0	1.93	.5		1.43	.5	
3	3.45	2.0	1.88	.5		1.37	.2	
	3.28	.5	1.83	1.0		1.33	.2	
1	2.99	5.0	1.80	.3		1.305	.2	
	2.86	1.0	1.725	2.0		1.275	.2	
	2.67	1.0	1.64	.5		1.202	.2	
	2.41	1.0	1.595	.3		1.095	.2	
	2.27	2.0						

Fe-Mn 93. Löllingite, FeAs_2 . Silver Center, Ontario.

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.45	.5	1	2.425	4.0	3	1.81	1.0
	2.83	.5		2.192	.2		1.628	.5
2	2.665	1.0		2.092	.2		1.340	.3
	2.54	.2		2.025	.5		1.215	.2

Cu-Ni 94. Lorandite, $\text{Tl}_2\text{S} \cdot \text{As}_2\text{S}_3$. Allchar, Macedonia. M-99

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	5.10	.5	2.28	.5		1.43	.2	
	4.40	.2	2.05	.5		1.41	.2	
	4.05	.5	1.94	.3		1.380	.2	
1	{ 3.65 }	5.0	1.84	.5		1.320	.2	
	{ 3.50 }		1.78	.3		1.271	.2	
	3.15	.5	1.74	.3		1.217	.2	
3	2.95	2.0	1.65	.5		1.148	.2	
2	2.85	3.0	1.585	.3		1.100	.3	
	2.74	1.0	1.541	.3		1.063	.2	
	2.61	1.0	1.510	.3		1.021	.2	
	2.40	.5	1.470	.5		.995	.2	
	2.34	.3						

*Fe— 95. Magnetite, Fe_3O_4 . Mineville, New York. M-101

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
3	2.96	1.0		2.085	1.0	2	1.475	2.0
	2.79	.5		1.71	.5		1.275	.3
1	2.53	5.0		1.62	1.0		1.09	.3

Co— 96. Marcasite, FeS_2 . Creighton, Ontario.

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
3	3.47	3.0	2	1.762	4.0		1.158	1.0
1	2.715	6.0		1.692	1.0		1.092	1.0
	2.42	2.0		1.600	2.0		1.033	1.0
	2.32	2.0		1.520	2.0		.991	1.0
	1.925	1.0		1.370	1.0		.957	3.0

*Cu— 97. Maucherite, Ni_3As_2 . Sudbury, Ontario.

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.18	1.0	3	1.73	7.0		1.14	1.0
1	2.72	10.0		1.638	1.0		1.118	1.0
	2.395	1.0		1.515	.5		1.19	1.0
2	2.035	9.0		1.46	2.0		1.075	.5
	1.902	2.0		1.22	2.0		1.048	.5

Cu-Ni 98. Melonite, Ni_2Te_3 . Boulder Co., Colorado. M-105A

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.33	1.0	2	1.930	4.0		1.318	.2
1	2.82	8.0		1.592	2.0		1.228	2.0
	2.63	1.0		1.555	3.0		1.135	.2
	2.35	2.0		1.442	.3		1.086	.2
3	2.075	3.0		1.410	.3		1.024	.2
	2.030	.5						

Cu-Ni 99. Meneghinite, $4\text{PbS} \cdot \text{Sb}_2\text{S}_3$. Marble Lake, Frontenac Co., Quebec. M-106

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.45	1.0		2.07	2.0		1.682	.5
2	3.24	3.0		1.97	1.0		1.630	.3
	3.05	1.0		1.93	.5		1.480	.3
1	2.90	4.0		1.882	1.0		1.441	.2
3	2.74	2.0		1.840	.3		1.422	.5
	2.64	1.0		1.800	1.0		1.395	2.0
	2.36	.5		1.785	.3		1.322	.3
	2.24	1.0		1.745	.5		1.240	.5
	2.17	.5		1.715	1.0		1.199	1.0

*Cu-Ni 100. Metacinnabar, HgS. Reddington Mine, Lake Co., California. M-107

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
1	3.36	10.0	1.69	1.0		1.192	1.0	
	2.92	2.0	1.461	.5		1.125	1.0	
2	2.07	5.0	1.34	2.0		.988	.5	
3	1.77	5.0	1.31	.5		.925	.3	

Cu-Ni 101. Miargyrite, AgS·Sb₂S₃. Zacatecas, Mexico. M-108

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
2	3.42	4.0	1.910	1.0		1.330	.3	
	3.16	1.0	1.800	2.0		1.301	.2	
	3.08	1.0	1.715	.5		1.285	.2	
1	2.88	5.0	1.682	1.0		1.250	.5	
3	2.74	3.0	1.625	.5		1.228	.5	
	2.64	.5	1.588	.5		1.145	.3	
	2.20	.5	1.550	.5		1.130	.3	
	2.01	2.0	1.425	.3		1.105	.2	
	1.965	2.0	1.415	.5		1.065	.2	
			1.372	.3				

*Fe— 102. Moschellandsbergite, Ag₂Hg₃. Moschellandsberg, Germany. Type material

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	2.91	.3	1.555	.2		1.192	.5	
	2.85	.5	1.538	.2		1.175	1.0	
	2.65	1.0	1.497	.5		1.158	2.0	
	2.57	2.0	1.470	1.0		1.142	1.0	
1	2.34	6.0	1.437	2.0		1.110	.3	
	2.22	1.0	1.410	2.0		1.100	.5	
	2.115	1.0	2	1.360	4.0	1.088	.5	
	1.95	2.0	1.332	1.0		1.076	1.0	
	1.710	1.0	1.268	2.0		1.054	1.0	
	1.660	2.0	3	1.229	3.0	1.030	2.0	
	1.620	.3						

Cu— 103. Millerite, NiS. Sudbury, Ontario.

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	4.80	2.0	1.805	1.0		1.197	.2	
	3.05	.2	1.730	2.0		1.170	.2	
	2.94	1.0	1.625	.5		1.140	.2	
1	2.77	5.0	1.595	1.0		1.108	.2	
3	2.50	3.0	1.540	1.0		1.102	.2	
	2.39	.2	1.400	.2		1.080	.2	
	2.22	3.0	1.380	.3		1.028	.3	
	2.05	.3	1.322	.2		.978	.2	
	2.00	.2	1.295	.3		.925	.2	
	1.91	.2	1.251	.3		.908	.2	
2	1.85	4.0	1.205	.2				

Cu-Ni 104. Molybdenite, MoS_2 , Ogden Mine, New Jersey. H-88915

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	6.61	3.0	3	1.530	6.0		1.021	1.0
	5.63	5.0		1.475	.3		1.002	2.0
	2.74	2.0		1.365	.3		.968	.5
	2.66	.5		1.335	2.0		.953	2.0
	2.49	1.0		1.295	2.0		.912	.5
1	2.27	8.0		1.251	2.0		.901	.3
	2.040	2.0		1.222	.3		.894	2.0
2	1.820	7.0		1.195	1.0		.865	1.0
	1.635	.5		1.100	2.0		.858	.5
	1.578	2.0		1.034	3.0		.834	.2

Cu-Ni 105. Nagyagite, Pb, Au, Te, S. Nagyág, Transylvania. M-112

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.62	1.0	3	2.09	4.0		1.360	.3
	3.40	3.0		1.835	2.0		1.315	.3
2	3.02	7.0		1.790	1.0		1.215	.3
1	2.83	8.0		1.715	4.0		1.142	.2
	2.65	.3		1.518	1.0		1.078	.2
	2.43	2.0		1.475	1.0			

Cu— 106. Niccolite, NiAs. Bebra, Hesse, Germany. M-114A

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	4.10	.2		2.16	.2		1.245	.5
	3.10	.3	2	1.95	5.0		1.065	.5
	2.94	.3	3	1.795	3.0		1.028	.3
1	2.64	6.0		1.475	1.0		.964	.2
	2.49	.2		1.320				

*Cu-Ni 107. Orpiment, As_2S_3 , Kurdistan. M-116

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
1	4.80	6.0		2.29	1.0		1.50	.2
	4.40	.3		2.22	.2		1.442	.2
	3.95	1.0		2.10B	.5		1.381	.2
	3.65	1.0		2.02	.3		1.320	.2
	3.17	1.0		1.90	.5		1.292	.2
2	2.82	3.0		1.87	.5		1.170	.2
3	2.70	3.0		1.74	1.0		1.100	.2
	2.55	.5		1.68	1.0		1.060	.2
	2.43	2.0		1.63	.2		1.002	.2

Cu-Ni 108. Pearceite, $8\text{Ag}_2\text{S} \cdot \text{As}_2\text{S}_3$. M-117A

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
3	3.09	.3		2.72	.2		2.18	.2
2	3.00	.5		2.52	.2		2.01	.2
1	2.84	1.0		2.34	.2		1.86	.2

*Cu-Ni 109. Penroseite, $5(\text{Ni}, \text{Co})\text{Se}_2 \cdot 2\text{PbSe}_2 \cdot 3\text{CuSe}$. Colquechaca, Bolivia.

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.50	2.0		1.81	4.0		1.115	1.0
	3.01	2.0		1.665	2.0		1.095	.3
1	2.68	6.0		1.602	2.0		1.062	1.0
2	2.45	5.0		1.555	.2		.974	.5
	2.14	2.0		1.510	.2		.914	.2
	2.00	.2		1.310	1.0		.896	.1
	1.93	.2		1.155	1.0			

*Fe-Mn 110. Pentlandite, $(\text{Fe}, \text{Ni})_9\text{S}_8$. Sudbury, Ontario.

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.54	.3		2.13	.1		1.25	1.0
	3.34	.3	3	1.95	3.0		1.225	.3
2	3.03	4.0	1	1.77	6.0		1.155	.2
	2.89	2.0		1.695	.2		1.069	.1
	2.51	.2		1.525	.3		1.049	.1
	2.30	1.0		1.515	.3		1.022	1.0
	2.095	.1		1.305	1.0			

Cu-Ni 111. Petzite, $(\text{Ag}, \text{Au})_2\text{Te}$. Upper Canada Mine, Ontario.

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.64	1.0		1.89	2.0		1.407	.3
	2.99	1.0		1.83	1.0		1.385	1.0
1	2.77	6.0		1.56	.5		1.315	2.0
	2.68	.2		1.525	.5		1.295	.3
	2.43	2.0		1.49	.3		1.275	.5
	2.31	2.0		1.465	.3		1.205	.3
2	2.11	3.0		1.435	.3		1.172	.3
3	2.03	3.0						

Cu-Ni 112. Plagionite, $5\text{PbS} \cdot 4\text{Sb}_2\text{S}_3$. Wolfsberg, Harz, Germany. M-120A

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.92	1.0		2.05	.5		1.78	.3
1	3.42	4.0	3	1.99	1.0		1.715	.5
2	2.78	3.0		1.89	.5		1.460	.5
	2.14	1.0		1.825	.5		1.345	.5

Cu-Ni 113. Polybasite, $8\text{Ag}_2\text{S} \cdot \text{Sb}_2\text{S}_3$. Pillow's Lake, Nevada. M-123

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.11	.5		2.22	.2		1.675	.5
3	2.94	2.0		2.06	.2		1.63	.3
1	2.81	4.0		1.99	1.0		1.49	.2
2	2.47	3.0		1.85	1.0		1.45	.1
	2.37	.5		1.75	.5		1.41	.1
	2.30	.5						

Co— 114. Polydymite, Ni_3S_4 . Grunau Mine, Siegen, Westphalia. U. S. National Museum No. 48491

(Pattern identical to that of violarite)

Cu-Ni 115. Proustite, $3\text{Ag}_2\text{S} \cdot \text{As}_2\text{S}_3$. Cobalt, Ontario. M-126E

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
1	3.20	6.0	2.08	.5		1.57	.3	
3	2.75	2.0	1.94	1.0		1.52	.3	
2	2.53	4.0	1.73	.3		1.43	.3	
	2.27	.5	1.64	.3				

Cu-Ni 116. Pyrargyrite, $3\text{Ag}_2\text{S} \cdot \text{Sb}_2\text{S}_3$. Himmelfurst mine, Freiburg, Germany. M-128

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.35	2.0	2.00	1.0		1.530	.5	
3	3.20	5.0	1.960	1.0		1.458	.3	
1	2.79	7.0	1.865	1.0		1.402	.5	
2	2.55	6.0	1.750	1.0		1.350	.3	
	2.26	1.0	1.680	1.0		1.262	1.0	
	2.12	1.0	1.600	1.0		1.210	.3	

*Cu-Ni 117. Pyrite, FeS_2 , Sudbury, Ontario.

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.10	.5	1.522	.5		1.013	.3	
2	2.76	3.0	1.460	.5		.990	.3	
3	2.46	3.0	1.224	.3		.961	.5	
	2.24	1.0	1.195	.3		.907	.5	
	1.93	2.0	1.160	.3		.880	.5	
	1.82	.5	1.120	.3		.825	.5	
1	1.645	4.0	1.050	1.0		.817	.3	
	1.585	.3	1.028	.3		.807	.3	

*Fe— 118. Pyrolusite, MnO_2 . M-193A

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.44	1.0	2.11	3.0		1.435	2.0	
1	3.11	10.0	1.97	1.0		1.395	.2	
	2.65	.5	1.795	1.0		1.305	2.0	
3	2.41	5.0	2	1.625	6.0	1.047	1.0	
	2.20	.5	1.560	2.0				

*Co— 119. Pyrrhotite, Fe_{1-x}S . Noranda, Quebec.

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	2.97	1.0	3	1.718	3.0	1.067	.5	
2	2.63	4.0	1.612	.5		1.045	2.0	
	2.45	.2	1.428	.7		.990	1.0	
	2.26	.2	1.315	1.0		.968	1.0	
1	2.062	8.0	1.170	.5		.908	2.0	
	1.88	.2	1.10	3.0				

*Cu— 120. Rammelsbergite, NiAs_2 . Eisleben, Germany.

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.60	.3		1.578	2.0		1.066	3.0
	2.90	.5		1.515	2.0		1.046	3.0
3	2.76	4.0		1.422	4.0		1.030	1.0
2	2.485	5.0		1.347	1.0		1.020	3.0
	2.415	3.0		1.280	.5		1.008	4.0
	2.32	.3		1.265	.5		.999	.5
	2.17	1.0		1.241	.5		.987	1.0
	1.985	1.0		1.228	3.0		.972	4.0
1	1.833	8.0		1.157	4.0		.947	4.0
	1.730	1.0		1.132	.2		.934	.5
	1.670	3.0		1.112	2.0		.920	3.0
	1.610	1.0		1.092	2.0			

*Cu— 121. Pararammelsbergite, NiAs_2 . Elk Lake, Ontario. Type material

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
2	2.86	3.0		1.595	.5		1.227	.5
1	2.55	8.0		1.537	1.0		1.135	.3
3	2.37	2.0		1.481	.3		1.103	.3
	2.005	2.0		1.440	.3		1.060	.5
	1.82	2.0		1.382	.3		1.047	.3
	1.735	2.0		1.320	.5		1.017	1.0
	1.660	.3		1.258	.2			

Cu-Ni 122. Rathite, $3\text{PbS} \cdot 2\text{As}_2\text{S}_3$. Binnenthal, Switzerland. M-132

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	4.1	.5	3	2.32	1.0		1.78	.2
	3.6	.3		2.22	.5		1.515	.2
	3.4	.5		2.08	.5		1.455	.2
	3.17	.5		2.02	.3		1.415	.2
1	2.96	2.0		1.92	.5		1.365	.2
2	2.72	2.0		1.82	.3			

Cu-Ni 123. Realgar, AsS_3 . Felsőbánya, Hungary. M-133

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	5.95	.3		2.60	.3		1.85	.5
1	5.40	3.0		2.48	.5		1.67	.5
	4.05	.3		2.40	.2		1.63	.3
2	3.15	3.0		2.23	.3		1.58	.2
3	2.93	3.0		2.18	.3		1.51	.2
	2.71	3.0		2.12	.5		1.47	.2

Cu-Ni 124. Rezbanyite, $2\text{PbS} \cdot 3\text{Sb}_2\text{S}_3$. Rezbánya, Hungary. M-135

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
3	3.60	2.0	2.18	1.0		1.676		.5
1	3.22	3.0	2.05	.3		1.625		.5
2	3.01	3.0	1.965	2.0		1.460		.3
	2.85B	1.0	1.915	.5		1.382		.2
	2.74	.5	1.800	.5		1.275		.2
	2.63	.5	1.730	.5		1.251		.5

*Cu-Ni 125. Rickardite, Cu_4Te_3 . Vulcan Mine, Gunnison Co., Colorado. M-136

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
2	3.32	4.0	1.810	.5		1.425		.2
		.5	1.705	.5		1.340		.2
3	2.55	1.0	1.665	.2		1.158		.3
1	2.06	3.0	1.580	.2		1.120		.3
	1.99	2.0	1.532	.2		1.084		.2

Cu-Ni 126. Samsonite, $2\text{Ag}_2\text{S} \cdot \text{MnS} \cdot \text{Sb}_2\text{S}_3$. Andreasberg, Harz, Germany. H-82439

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	6.2	.3	2.24	.3		1.402		.3
	5.22	.3	2.17	.3		1.370		.3
	4.08	.3	2.08	.5		1.345		.2
	3.73	.3	2.01	.3		1.295		.2
	3.28	.5	1.93	.5		1.255		.2
1	3.17	2.0	1.84	.5		1.235		.2
2	2.99	2.0	1.81	.5		1.205		.2
3	2.85	1.0	1.755	.5		1.165		.2
	2.70	.5	1.620	.5		1.133		.2
	2.57	1.0	1.545	.3		1.108		.2
	2.47	.5	1.48	.2		1.095		.2
	2.42	1.0	1.44	.3		1.082		.2
	2.32	.3						

Co— 127. Safflorite, CoAs_2 . Quartzburg, Grant Co., Oregon. U. S. National Museum.

No. 84753

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	2.84	.5	3	1.635	4.0		1.100	1.0
1	2.60	10.0		1.565	1.0		1.075	1.0
2	2.37	4.0		1.500	2.0		1.048	1.0
	2.04	.3		1.275	1.0		.975	.5
	1.94	.5		1.160	.5		.965	.5
	1.87	3.0						

Cu-Ni 128. Sartorite, $\text{PbS} \cdot \text{As}_2\text{S}_3$. Binnenthal, Switzerland. M-139A

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	4.1	.3		2.62	1.0		1.94	.5
	3.87	.3		2.54	.3		1.86	.3
1	3.48	3.0		2.45	.3		1.79	.2
	3.23	.5		2.32	1.0		1.73	.2
2	2.95	2.0		2.10	.5		1.55	.2
3	2.76	2.0						

Cu-Ni 129. Schapbachite, $\text{Ag}_2\text{S} \cdot \text{PbS} \cdot \text{Bi}_2\text{S}_3$. Schapbach, Baden, Germany. M-141A

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
3	{ 3.42 }	3.0		1.705	2.0		1.255	.2
2	{ 3.28 }	4.0		1.640	.3		1.205	.2
1	{ 2.95 }	2.0		1.476	.3		1.045	.2
	{ 2.82 }	5.0		1.410	.2		.984	.2
	2.08	2.0		1.355	.2		.934	.2
	2.00	2.0		1.320	.5		.891	.2
	1.78	2.0						

If the doublets indicated by the brackets are not resolved, the apparent order of strongest lines is: (1) 3.35, (2) 2.88, (3) 2.08.

Cu-Ni 130. Schirmerite, $3(\text{As}_2, \text{Pb})\text{S} \cdot 2\text{Bi}_2\text{S}_3$, Lake City, Colorado. M-16A

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.67	2.0		2.03	1.0		1.318	.3
1	3.00	10.0		1.89	1.0		1.296	.3
	2.82	.2	2	1.83	7.0		1.275	.3
	2.76	.3		1.775	.5		1.239	.5
	2.58	2.0		1.680	1.0		1.205	.5
	2.44	1.0		1.630	.3		1.189	.5
	2.32	.5	3	1.560	5.0		1.116	.3
	2.22	.5		1.495	.2		1.092	.3
	2.12	.5		1.465	.3		1.057	.5

Cu-Ni 131. Seligmannite, $\text{Cu}_2\text{S} \cdot 2\text{PbS} \cdot \text{As}_2\text{S}_3$. Butte, Montana. H-85708

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	5.80	.5		2.23	.3		1.450	.2
	4.75	.2		2.16	.3		1.418	1.0
	4.35	1.0		2.09	.5		1.385	1.0
	4.10	.5		1.97	.5		1.361	.5
2	3.85	3.0		1.94	.5		1.337	.3
	3.66	1.0		1.84	1.0		1.325	.2
	3.25	1.0	3	1.77	2.0		1.282	.2
	2.97	1.0		1.725	.2		1.248	.2
	2.90	.3		1.66	1.0		1.225	.3
	2.82	.4		1.635	1.0		1.212	.2
1	2.72	4.0		1.590	.2		1.145	.3
	2.65	1.0		1.550	1.0		1.114	.3
	2.57	2.0		1.495	.2		1.102	.3
	2.36	1.0		1.482	.2		.985	.3
	2.28	.3						

Cu-Ni 132. Semseyite, $9\text{PbS} \cdot 4\text{Sb}_2\text{S}_3$. Rezbánya, Hungary. M-143

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.85	1.0		2.47	.3		1.81	.2
	3.60	.2		2.25	1.0		1.72	.2
1	3.28	5.0		2.17	.5		1.635	.2
2	3.00	3.0		2.06	.5		1.490	.2
3	2.74	1.0		1.93	.2		1.362	.2

Cu— 133. Siegenite, $(\text{Co}, \text{Ni})_3\text{S}_4$. U. S. National Museum. C-529

Identical to patterns of violarite, polydymite, carrollite.

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.36	.2	3	2.36	1.0		1.83	.3
1	2.85	2.0		2.04	.2	2	1.67	2.0

*Cu-Ni 134. Silver, Ag.

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
1	2.35	9.0	2	1.228	6.0		.936	5.0
3	2.04	5.0		1.176	2.0		.912	5.0
	1.44	4.0		1.018	1.0		.8335	5.0

Cu— 135. Skutterudite, $(\text{Co}, \text{Ni})\text{As}_3$. Skutterud, Norway. M-145

Identical to pattern of smaltite-chloanthite.

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.40	.5	3	1.62	3.0		1.005	.2
	2.90	.5		1.42	1.0		.975	.3
1	2.64	10.0		1.38	.2		.965	.3
	2.45	.2		1.32	.2			1.0
	2.21	2.0		1.22	1.0		.916	.3
	2.08	.2		1.20	.2		.855	1.0
	1.96	.3		1.142	.2		.840	.5
2	1.86	3.0		1.125	.2		.805	.2
	1.76	.5		1.085	1.0		.790	1.0
	1.70	1.0		1.050	.3			

*Cu-Ni 136. Sperrylite, PtAs_2 . Sudbury, Ontario.

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.38	1.0		1.30	.5		.908	3.5
	2.94	2.0		1.272	.3		.898	3.0
	2.64	1.0		1.220	3.0		.888	.3
	2.41	1.0	2	1.144	4.0		.880	.3
	2.10	2.0		1.105	1.0		.835	4.0
1	1.788	4.0		1.088	1.0		.827	4.0
	1.720	.5	3	1.050	3.0		.819	1.0
	1.65	.5		1.005	2.5		.812	1.0
	1.59	1.0		.990	.3		.797	4.0
	1.37	1.0		.966	1.0		.777	9.0
	1.33	2.0		.941	3.0		.775	6.0

*Cu-Ni 137. Sphalerite, ZnS. Butte, Montana.

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.95	.5		1.555	.5		1.041	2.0
1	3.12	6.0		1.350	2.0		.966	1.0
	2.70	2.0		1.241	3.0		.914	2.0
2	1.91	5.0		1.210	.5		.855	1.0
3	1.63	4.0		1.105	3.0			

*Cu-Ni 138. Stannite, $\text{Cu}_2\text{S} \cdot \text{FeS} \cdot \text{SnS}_2$. Cairn Brea, Redruth, Cornwall, England. M-149
Note similarity to sphalerite pattern.

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
1	3.11	8.0	2	1.91	5.0		1.238	.5
	2.82	1.0		1.80	.2		1.105	.5
	2.70	.5	3	1.630B	2.0		1.042	.3
	2.20	.3		1.560	.3		.916	.2
	1.99	1.0						

Cu-Ni 139. Stephanite, $5\text{Ag}_2\text{S} \cdot \text{Sb}_2\text{S}_3$. Freiberg, Saxony, Germany. M-151

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.31	.5		2.18	1.0		1.515	.5
1	3.06	4.0		2.13	1.0		1.465	.3
3	2.90	2.0		2.01	.3		1.418	.2
	2.75	1.0		1.96	.3		1.390	.3
2	2.56	3.0		1.86	.5		1.345	.3
	2.49	.5		1.84	.5		1.305	.2
	2.42	1.0		1.78	.5		1.260	.2
	2.33	.5		1.63B	.5		1.195	.5

Cu-Ni 140. Sternbergite, $\text{AgFe}_2\text{S}_{3-4}$. Joachimsthal, Bohemia. M-152

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	4.75	.5		2.64	1.0		1.79	2.0
1	4.25	6.0		2.36	.5		1.66	1.0
2	3.25	3.0		1.945	1.0		1.59	.5
3	2.79	3.0		1.895	1.0			

*Cu-Ni 141. Stibnite, Sb_2S_3 . Nmokain, Araigai, Iyo, Japan. H-81565

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	5.60	2.0		1.990	.3		1.291	.5
	5.00	2.0	2	1.940	4.0		1.241	.5
	3.95	1.0		1.885	.3		1.202	.5
1	3.55	6.0		1.785	.3		1.188	.5
	3.11	2.0		1.725	2.0		1.131	.5
	3.05	3.0	3	1.690	4.0		1.112	.5
	2.77	3.0		1.540	1.0		1.083	.5
	2.67	.5		1.525	1.0		1.060	.5
	2.52	3.0		1.485	.5		.985	.3
	2.42	1.0		1.442	.5		.959	.5
	2.28	1.0		1.400	.5		.943	.3
	2.23	2.0		1.312	.5		.915	.5
	2.10	3.0						

Cu-Ni 142. Stromeayerite, $(\text{CuAg})_2\text{S}$

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.06	.5		2.34	1.0		1.99	.5
1	2.96	3.0		2.30	1.0		1.91	.3
2	2.79	3.0		2.16	.5		1.82	.5
3	2.47	1.0		2.09	.3		1.67	.3

Cu-Ni 143. Sulvanite, Cu_3VS_4 . Burra Burra, South Australia. H-85259

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
2	5.2	6.0		1.620	4.0		1.036	.5
	4.15	.5		1.495	1.0		1.000	.2
	3.70	.3		1.345	1.0		.951	.5
3	3.11	6.0		1.302	1.0		.936	.3
	2.84	.3		1.235	1.0		.909	.3
	2.69	1.0		1.175	.5		.851	.2
1	2.40	7.0		1.098	2.0		.812	.3
	1.799	2.0						

Cu-Ni 144. Sylvanite, $(\text{Au, Ag})\text{Te}_2$. Nagyág, Transylvania. M-159

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	4.7	.5	2	2.12	6.0		1.525	1.0
	3.95	1.0		2.07	1.0		1.475	1.0
1	3.05	8.0		1.99	.5		1.410	.2
3	2.96	3.0		1.835	.3		1.352	.3
	2.83	.5		1.790	.5		1.322	.3
	2.35	.2		1.695	1.0		1.207	.3
	2.25	1.0						

*Cu-Ni 145. Tellurium, Te. Good Hope Mine, Vulcan, Colorado. M-162

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.85	1.0		1.61	2.0		1.170	3.0
1	3.22	9.0		1.47	1.0		1.125	.3
2	2.33	4.0		1.445	.5		1.048	.3
3	2.22	3.0		1.410	1.0		1.037	.2
	2.07	1.0		1.375	1.0		1.005	.2
	1.965	1.0		1.300	.5		.898	.2
	1.82	2.0		1.252	.3		.864	.2
	1.77	.5		1.230	.3			

Cu-Ni 146. Tellurobismuthite, Bi_2Te_3 . Whitehorn, Colorado.

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
1	3.20	10.0		1.61	4.0		1.265	.5
	2.50	.2		1.56	.2		1.208	.3
2	2.37	8.0		1.485	4.0		1.190	.3
3	2.19	8.0		1.410	.3		1.072	.5
	2.02	2.0		1.395	3.0		1.040	.5
	1.81	4.0		1.340	1.0		.992	.5
	1.70	1.0		1.298	2.0			

*Cu-Ni 147. Tennantite. $5\text{Cu}_2\text{S} \cdot 2(\text{Cu, Fe, Zn})\text{S} \cdot 2\text{As}_2\text{S}_3$, Cornwall, England. H-87984

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	4.16	2.0		1.77	.3		1.142	.3
	3.70	.5		1.71	.3		1.102	.3
1	2.95	9.0		1.655	1.0		1.042	2.0
	2.74	.5	3	1.541	6.0		.982	.5
	2.56	3.0		1.475	.3		.974	.5
	2.41	2.0		1.445	.5		.910	.5
	2.09	.5		1.277	1.0		.902	.3
	2.01	1.0		1.222	.3		.868	.3
	1.87	3.0		1.190	.5		.863	.3
2	1.81	6.0		1.172	1.0			

*Cu-Ni 148. Tenorite, CuO. Vesuvius, Italy. H-83359

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
1	2.48	8.0		1.51	2.0		1.090	1.0
2	2.32	8.0		1.41	1.0		.978	1.0
3	1.87	2.0		1.375	2.0		.918	.5
	1.71	.5		1.305	.5		.887	.5
	1.58	1.0		1.260	2.0		.855	.3

Cu-Ni 149. Tetradyomite, $\text{Bi}_2(\text{Te,S})_3$. Schubkau, Hungary. H-81609

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
1	3.12	8.0		1.95	1.0		1.440	.1
	2.78	.3		1.84	.1		1.350	.5
	2.60	.3		1.76	1.0		1.300	.3
3	2.30	2.0		1.65	.2		1.255	.2
2	2.12	3.0		1.56	1.0			

Cu-Ni 150. Tetrahedrite, $5\text{Cu}_2\text{S} \cdot 2(\text{Cu, Fe, Zn})\text{S} \cdot 2\text{Sb}_2\text{S}_3$. Bingham, Utah. H-82545

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	4.15	.5		1.66	1.0		1.190	.5
1	2.96	8.0	3	1.54	5.0		1.175	1.0
	2.56	2.0		1.475	.5		1.105	.5
	2.42	1.0		1.445	.5		1.044	2.0
	2.01	1.0		1.280	1.0		.984	.5
	1.87	1.0		1.222	1.0		.976	.5
2	1.81	6.0						

Cu-Ni 151. Tiemannite, HgSe. Marysvale, Utah. H-81896

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
1	3.38	10.0		1.365	4.0		.950	3.0
	2.95	2.0		1.22	4.0		.917	2.0
2	2.10	8.0		1.15	3.0		.842	2.0
3	1.79	8.0		1.06	2.0		.804	3.0
	1.72	1.0		1.015	2.0		.785	2.0
	1.49	2.0						

Fe— 152. Troilite, FeS. California. H-90018

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	5.11	.2	1	2.10	8.0		1.450	.5
	4.72	.3		1.912	.5		1.370	1.0
	3.82	.3		1.900	.3		1.320	.5
3	2.98	3.0		1.755	.3		1.120	1.0
2	2.68	5.0		1.722	3.0		1.107	1.0
	2.54	.3		1.638	.5		1.054	1.0
	2.325	2.0		1.472	1.0			

Cu-Ni 153. Tungstenite, WS₂. Cottonwood, Utah. M-216

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
1	6.2	9.0		1.58	2.0		1.25	.5
2	2.68	6.0		1.52	2.0		1.10	1.0
3	2.28	2.0B		1.40	.3		1.025	1.0
	2.05	1.0		1.35	.5		1.000	1.0
	1.88	1.0B		1.30	.3		.960	.5B

*Cu— 154. Ullmanite, NiSbS. Wissen sur le Sieg, Prussia. M-169

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	4.15	1.0		1.580	.5		1.080	.3
	3.40	.2		1.475	.2		1.045	.5
	2.94	1.0		1.430	.3		1.015	.2
1	2.64	8.0		1.390	.3		.988	.2
2	2.41	3.0		1.315	.2		.971	.2
	2.08	.5		1.290	.5		.958	.3
	1.98	.5		1.260	.3		.898	.2
	1.87	.5		1.159	.3		.888	.2
3	1.78	3.0		1.135	.3		.880	.3
	1.701	.2		1.120	.2		.811	.3
	1.640	1.0		1.098	.5			

*Cu-Ni 155. Umangite, Cu₃Se₂. Rivja, Argentina. H-81762

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
1	3.6	6.0		1.42	1.0		1.015	.5
2	3.15	6.0		1.35	1.0		1.000	.5
	2.85	1.0		1.27	.5		.965	.5
	2.58	1.0		1.23	.5		.941	3.0
	2.40	.5		1.20	2.0		.912	.3
	2.26	3.0		1.185	2.0		.904	.3
	2.14	2.0		1.165	2.0		.895	.5
	2.02	3.0		1.130	.5		.870	.5
	1.91	3.0		1.095	.5		.818	3.0
3	1.83	4.0		1.060	.5		.793	3.0
	1.77	4.0		1.050	.3		.788	3.0
	1.64	1.0		1.035	1.0		.781	3.0
	1.55	1.0						

Cu— 156. Violarite, $(\text{NiFe})_3\text{S}_4$. Vermilion Mine, Sudbury, Ontario.

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.36	1.0	2	1.678	7.0		1.059	.5
1	2.86	8.0		1.445	.5		.993	.5
3	2.37	3.0		1.370	.5		.969	2.0
	2.08	.3		1.234	.5		.915	.5
	1.93	.5		1.183	.5		.838	.2
	1.83	2.0		1.097	.5			

Cu-Ni 157. Weissite, Cu_5Te_3 ? Vulcan mine, Gunnison Co., Colorado. M-136

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.58	2.0		2.175	.2		1.755	.1
2	3.22	3.0	1	2.080	4.0		1.438	.3
	2.55	.5	3	2.000	3.0		1.341	.1
	2.28	.3		1.800	1.0		1.184	.1

Cu-Ni 158. Wehrlite, uncertain silver bismuth telluride, Deutsch Pilsen, Hungary. H-81611

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
1	3.22	6.0		1.40	1.0		1.075	.2
2	2.35	3.0		1.302	.5		1.040	.2
3	2.21	3.0		1.275	.3		.998	.2
	1.99	1.0		1.180	.3		.983	.2
	1.82	1.0		1.140	.3		.942	.2
	1.61	1.0		1.105	.2		.922	.2
	1.478	1.0		1.082	.2			

Cu— 159. Willyamite, $(\text{Co}, \text{Ni})\text{SbS}$. Broken Hill, N.S.W., Australia. M-175

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	4.15	1.0		1.630	1.0		1.132	.3
	3.38	.5		1.570	1.0		1.095	.5
	2.92	1.0		1.530	.2		1.072	.3
1	2.62	6.0		1.470	.3		1.040	.2
2	2.40	3.0		1.420	.2		.968	.2
	2.07	.3		1.384	.2		.896	.2
	1.97	.3		1.315	.2		.880	.2
	1.86	.3		1.285	.5			
3	1.770	2.0		1.255	.3			
	1.700	.3		1.155	.3			

Cu-Ni 160. Wittichenite, $3\text{Cu}_2\text{S} \cdot \text{Bi}_2\text{S}_3$. Wittichen, Baden, Germany. H-89173

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
1	3.12	9.0		1.44	1.0		.995	.5
	2.80	.5		1.36	.5		.965	.5
3	2.32	2.0		1.32	1.0		.928	.3
	2.16	2.0		1.27	.5		.905	.3
	1.95	1.0		1.21	.5		.890	.3
	1.86	1.0		1.16	1.0		.878	.3
2	1.78	3.0		1.105	.3		.793	.3
	1.65	2.0		1.090	.3		.781	.3
	1.56	1.0		1.030	.5			

Cu-Ni 161. Wulfenite, PbMoO_4 . M-124

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
1	3.17	10.0	1.30	4.0			.945	3.0
	3.00	1.0	1.24	1.0			.918	1.0
	2.67	2.0	1.21	1.0			.890	.5
	2.35	.5	1.182	1.0			.880	.5
	2.20	.2	1.150	1.0			.868	.5
3	2.00	4.0	1.120	2.0			.857	.5
	1.96	2.0	1.075	1.0			.845	3.0
	1.77	4.0	1.045	2.0			.825	3.0
2	1.64	5.0	1.005	1.0			.811	3.0
	1.50	.2	.986	2.0			.800	3.0
	1.35	.2						

Fe—162. Wolframite, $(\text{Fe,Mn})\text{WO}_4$. Torrington Mine, N.S.W., Australia. M-219

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	4.72	1.0	3	2.18	2.0		1.503	1.0
	3.71	1.0		2.04	.5		1.445	.5
	3.21	1.0		1.986	.5		1.428	.5
1	2.917	4.0		1.866	.5		1.365	.5
	2.83	.5		1.810	.3		1.312	.3
	2.70	.5		1.758	1.0		1.178	.2
2	2.46	2.0		1.702	2.0		1.078	.2
	2.35	.3		1.585	.3		1.065	.2
	2.26	.2						

DOUBTFUL MINERALS

Cu-Ni 163. Algodonite, Cu_3As . M-110

The specimen studied is a bluish grey copper arsenide corresponding to the description of algodonite but showing only one phase even upon etching. Because of its blue color it is thought to be β -algodonite.

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	2.55	.2	2	2.02	3.0		1.18	.5
	2.38	.3		1.78	.3		1.15	.2
	2.21	.3	3	1.44	1.0		1.13	.2
1	2.08	3.0		1.33	.3			

Cu-Ni 164. Domeykite, Cu_3As . M-110

This specimen corresponds to the description of domeykite except that with KCN the mineral effervesces and stains black, bringing out grain structure.

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
3	2.25	2.0		1.54	.3		1.20	.5
2	2.13	3.0		1.45	.2		1.105	.5
1	2.00	8.0		1.30	.5		1.080	.2

UNIDENTIFIED MINERALS

During this investigation a few minerals have been encountered which cannot be identified. They give distinctive x -ray patterns and are regarded as independent species. Still other minerals have been encountered which are variations of recognized species. All these are listed below.

Cu-Ni 165. A Bi, S, Te-bearing mineral from Texas, identical with orueteite and grunlingite in the arrangement and relative intensity of lines but having a slightly larger unit cell. M-166B

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.70	1.0	2	2.31	5.0		1.580	3.0
	3.50	1.0	3	2.17	5.0		1.450	1.0
1	3.16	10.0		2.12	.5		1.380	2.0
	2.81	.3		1.96	1.0		1.275	.3
	2.64	1.0		1.795	4.0		1.245	.3
	2.41	.5						

Cu-Ni 166. A Cu, Fe, S-bearing mineral containing some tin, associated with chalcopyrite in the ore from Morococha, Peru. In polished section the mineral is orange colored. It shows extreme anisotropism, yielding brilliant colors. Pattern is very similar to sphalerite type.

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	3.8			2.22	.3		1.337	1.0
	3.28	.5		2.11	.2		1.258	1.0
1	3.08	6.0		1.965	.3		1.114	.3
	2.82B	1.0		1.930	.3		1.093	1.0
	2.68	1.0	2	1.890	4.0		1.029	.3
	2.49	1.0		1.642	.3		.946	.2
	2.38	1.0	3	1.613	3.0		.904	.2

Cu—167. Hauchecornite, M-74. This specimen from Wissen, Prussia, has tabular crystals resembling pyrrhotite in color, which contain Ni, Bi, and S. The mineral is anisotropic giving the colors blue, pale yellow, brown and white. Hardness, E. Etch reactions: HNO_3 , stains brown; HCl , KOH , FeCl_3 , and KCN , negative; HgCl_2 , marginal brown ring. The crystals are irregularly replaced by ullmanite and millerite, a fact which caused confusion when the crystals were first analyzed and the name hauchecornite was proposed. Later when the composite nature of the crystals was observed the species was discredited as a mixture. However, when sampled on a micro-scale the crystals prove to be a distinctive species yielding the following unique powder pattern:

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	5.08	.3		1.85	1.0		1.256	.3
	4.75	.3		1.80	1.0		1.245	2
	4.30	1.0		1.74	.3		1.210	.2
	3.60	1.0		1.71	.3		1.160	.3
	3.22	1.0		1.67	.2		1.151	.2
1.	2.77	4.0		1.565	.5		1.130	.2
	2.62	.5		1.505	.2		1.078	.3
	2.52	.5		1.390	.3		1.057	.3
2	2.37	2.0		1.342	.3		1.007	.2
3	2.28	2.0		1.305	.3		.913	.2
	2.06	.3		1.276	.2			

Cu-Ni 168. Von Diestite. M-237. This material from Sierra Blanca, Colorado, contains tabular crystals of steel grey color and metallic luster, which have one perfect cleavage providing flexible laminae. In polished section the mineral is galena-white; hardness A; anisotropic, giving the colors grey and brown. Nitric acid causes effervescence and stains it black; HCl and KCN, negative; FeCl₃, instantly stains iridescent; KOH and HgCl₂, negative. Gives microchemical tests for Bi, Te and S. The mineral is intimately associated with hessite and petzite which probably accounts for its original description as a silver bismuth telluride. Its powder pattern is similar to, but distinct, from the patterns of three other Bi, Te, S-bearing minerals included in this investigation, namely, tetradyomite, wehrlite, and oruetite-grunlingite. It is almost identical with that of tellurobismuthite and except for the sulphur would be identified as such.

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
	4.05	.3		1.85	1.0		1.312	1.0
	3.70	.5		1.81	2.0		1.290	1.0
1	3.20	9.0		1.69	.2		1.265	.5
2	2.36	4.0		1.602	3.0		1.138	.3
	2.27	2.0		1.48	2.0		1.072	.5
3	2.18	4.0		1.435	2.0		1.042	.3
	2.01	.5		1.395	2.0		.994	.3

Cu-Ni 169. Chalcocite (Digenite). The following pattern represents a so-called isometric chalcocite from the fire zone at Jerome, Arizona. It is quite different from normal chalcocite.

<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>	<i>O</i>	<i>d</i>	<i>I</i>
2	3.22	1.0		1.68	.5		1.075	.2
3	2.79	1.0		1.135	.2		1.066	.2
1	1.97	4.0						

PATTERN TYPES

The x-ray powder pattern given by certain simple structures is easily recognized from the arrangement of the lines in a distinctive sequence of spacings and intensities. It is thus possible to recognize a face centered or body centered cubic pattern, and others by inspection. A number of cases will be pointed out where two or more related minerals yield almost identical patterns, showing a slight difference in cell size only. There is little doubt in such cases but that the atomic structure is similar and variations are due to the substitution of an atom of one chemical element for that of another without distortion, other than an overall change in the size of the unit cell of the crystal. In studying the collection of patterns presented here several groups of minerals have been found to give the same type of powder pattern and it is believed that the atomic arrangement of minerals of such groups is fundamentally the same. Only a small fraction of the total number of patterns could be classified in this way, most of them are too complex for this and have no obvious relationship to one another. However, the following notes give the results of comparing the patterns of some groups of similar minerals.

Native Elements

Copper
Gold
Silver
Lead

<i>Galena Group</i>	<i>Chemical Type</i>	<i>A</i>	<i>B</i>
Galena	PbS		
Cerargyrite	AgCl		
Metacinnabar	HgS		
Tiemannite	HgSe		
Clausthalite	PbSe		

<i>Allaite Group</i>	<i>Chemical Type</i>	<i>A</i>	<i>B</i>
Altaite		Pb	Te
Alabandite		Mn	S

<i>Sphalerite Group</i>	<i>Chemical Type</i>	<i>A</i>	<i>B</i>
Sphalerite		Zn	S
Chalcopyrite		CuFe	S ₂
Stannite		Cu ₂ FeSn	S ₄
Famatinite		Cu ₃ Sb	S ₄
Germanite		Cu ₃ (FeGe)	S ₄
Colusite	(Cu, Fe, Mo, Sn)	(S, As, Te) ₃₋₄	

Niccolite, millerite, pyrrhotite, breithauptite, cinnabar, cubanite, sternbergite and covellite show no correspondence. Pyrrhotite and troilite are the same except for cell size.

<i>Tetradymite group</i>	<i>Chemical Type</i>	<i>A_m</i>	<i>B_n</i>	
Grunlingite		Bi ₄	TeS ₃	} Identical.
Orueteite				
Wehrlite		Bi, Te, S		Same cell but larger.
Tetradymite		Bi ₂	Te ₂ S	Very similar to the above but differs in the separation of a prominent pair of lines.
Von Diestite		Bi, Te, S		Similar but different.

Chemical Type A₂B

Chalcocite, and stromeyerite show no correspondence.

Chemical Type A₃B₂

Maucherite and wehrlite show no correspondence.

<i>Linnæite Group</i>	<i>Chemical Type</i>	<i>A₃</i>	<i>B₄</i>	
Linnæite		Co ₃	S ₄	} Identical patterns.
Siegenite		(Co, Ni) ₃	S ₄	
Carrollite		(Co, Cu) ₃	S ₄	
Polydymite		Ni ₃	S ₄	
Violarite		(Ni, Fe) ₃	S ₄	
Daubreeilite		FeCr ₂	S ₄	Same pattern, larger cell.

Chemical Type A_4B_3

Rickardite and weissite give very similar patterns which differ in detail.

<i>Stibnite Group</i>	<i>Chemical Type</i>	A_2	B_3	
Stibnite		Sb_2	S_3	} Identical except for cell size.
Bismuthinite		Bi_2	S_3	
Guanajuatite		Bi_2	$(Se, S)_3$	
Kermesite		Sb_2	S_2O	
Orpiment does not correspond.				

<i>Pyrite Group</i>	<i>Chemical Type</i>	A	B_2	
Pyrite		Fe	S_2	} Identical except for cell size.
Bravoite	(Fe, Ni)	S_2		
Hauerite	Mn	S_2		
Sperrylite	Pt	As_2		
Penroseite	(Ni, Cu)	Se_2		
Cobaltite		Co	AsS	} Identical except for cell size.
Gersdorffite		Ni	AsS	
Plessite	(Ni, Fe)	AsS		
Corynite		Ni	(As, Sb)S	
Kallilite		Ni	(Sb, Bi)S	
Ullmanite		Ni	SbS	
Willyamite	(Co, Ni)	SbS		

Marcasite Group. This group does not show any uniformity similar to the pyrite group. Safflorite and glaucodote are very similar but do not have a common cell. Marcasite, rammsbergite, and pararammsbergite give unique patterns not readily related to the rest of the group.

Ditelhvuide Group *Chemical Type $A B_2$*

Sylvanite, krennerite and calaverite are very similar. Melonite is different.

Smaltite, chloanthite, skutterudite. These minerals give the same pattern.

Sulphosal's In general they give very complex powder patterns in which similarities are not easily recognized.

Polybasite	AgSbS	}	Similar
Argyrodite	AgGeS		
Pearceite is different.			
Jordanite	Pb ₁ As ₇ S ₂₄	}	Nearly identical except for cell size.
Guitermannite	Pb ₁₀ As ₆ S ₁₉		
Geocronite	Pb ₈ Sb ₂ S ₈		
Meneghenite and kobellite are very similar; boulangerite is different.			
Emplectite	CuBiS ₂	}	Identical except for cell size.
Chalcostibite	CuSbS ₂		
Klaprotholite is similar; miargyrite, aramayoite, lorandite are all different.			
Jamesonite, dufrenoysite, kobellite and cosalite are all different.			
Bournonite	PbCuSbS ₃	}	Identical.
Seligmanite	PbCuAsS ₃		
Aikenite is quite different.			
Keeleyite	PbSb ₂ S ₄	}	Identical?
Boulangerite	Pb ₈ Sb ₄ S ₁₁		

A curious fact brought out during this comparison is the following:

Enargite	Cu_3AsS_4	} Identical except for cell size.
Greenockite	CdS	

SOME OBSERVATIONS AND CONCLUSIONS BASED ON THE STUDY OF MINERALS AND THEIR POWDER PATTERNS

Berthonite $(\text{Pb}, \text{Cu}_2)_2\text{Sb}_2\text{S}_6$

Bournonite PbCuSbS_3

Berthonite from the type locality of Slatá, Tunisia, gives the pattern of bournonite. Note that the properties of these two minerals are identical.

Ramdohrte $\text{Ag}_2\text{Pb}_3\text{Sb}_6\text{S}_{13}$

Andorite $\text{Ag}_2\text{Pb}_2\text{Sb}_6\text{S}_{12}$

The pattern given by a specimen of ramdohrte from Potosí, Bolivia, is the same as that of andorite. Ramdohrte needs further checking.

Beegerite $\text{Pb}_6\text{Bi}_2\text{S}_9$

A specimen from the Auld Lout Mine, Ouray, Colorado, contains two isotropic grey minerals, one lighter in color than the other. The pattern of the light grey mineral corresponds to schapbachite. The properties of these two minerals and qualitative analyses check except that schapbachite is anisotropic. The mineral (schapbachite) is apparently like pyrite in that it may or may not show anisotropism. The dark grey mineral has been identified as schirmerite, the properties of which in polished section are as follows: Isotropic; color, tetrahedrite grey; hardness, C; HNO_3 , light mottled stain; HCl , KCN , FeCl_3 , KOH and HgCl_2 , negative.

Kobellite $\text{Pb}_2(\text{Bi}, \text{Sb})_2\text{S}_6$

The properties of this mineral in polished section are as follows: Color, grey similar to galena; hardness, B; anisotropic giving light and dark grey; HNO_3 , quickly blackens; HCl , KCN , FeCl_3 , KOH , and HgCl_2 , negative.

TABLE 2. INDEX OF POWDER PATTERNS

Strongest Lines and their Relative Intensities			Name	Pattern Number (In Table 1)
1	2	3		
1.485 (9)	2.84 (8)	1.74 (7)	Lead	90
1.645 (4)	2.76 (3)	2.46 (3)	Pyrite	117
1.77 (6)	3.03 (4)	1.95 (3)	Pentlandite	110
1.788 (4)	1.144 (4)	1.050 (3)	Sperrylite	136
1.833 (8)	2.485 (5)	2.76 (4)	Rammelsbergite	120
1.90 (9)	2.82 (8)	3.02 (7)	Covellite	45
1.94 (8)	3.31 (2)	3.15 (2)	Bornite	20
1.95 (8)	1.865 (8)	2.38 (6)	Chalcocite	31
1.97 (4)	3.22 (1)	2.79 (1)	Chalcocite (isometric), Digenite	169
1.98 (7)	3.20 (4)	1.84 (3)	Berzelianite	17
2.00 (8)	2.13 (3)	2.25 (2)	Domeykite	164
2.02 (3)	2.82 (1)	3.10 (.5)	Chromite	35
2.03 (5)	2.49 (4)	2.76 (3)	Hausmannite	77
2.03 (3)	3.80 (3)	3.00 (3)	Cannizarite	27

TABLE 2. INDEX OF POWDER PATTERNS—*Continued*

Strongest Lines and their Relative Intensities			Name	Pattern Number (In Table 1)
1	2	3		
2.06 (3)	3.32 (4)	2.55 (1)	Rickardite	125
2.06 (8)	2.63 (4)	1.718 (3)	Pyrrhotite	119
2.08 (8)	1.81 (4)	1.275 (3)	Copper	42
2.08 (3)	2.02 (3)	1.44 (1)	Algodonite	163
2.08 (4)	3.22 (3)	2.00 (3)	Weissite	157
2.10 (8)	2.68 (5)	2.98 (3)	Troilite	152
2.22 (3)	2.10 (2)	1.815 (2)	Jordanite	83
2.22 (2)	1.82 (2)	3.18 (3)	Gütermannite	75
2.23 (5)	1.830 (3)	3.19 (1)	Geocronite	64
2.26 (4)	2.39 (2)	2.55 (1)	Dyscrasite	54
2.27 (8)	1.82 (7)	1.53 (6)	Molybdenite	104
2.27 (5)	3.20 (4)	1.435 (3)	Altaite	5
2.28 (10)	1.955 (7)	1.320 (4)	Coloradoite	39
2.34 (6)	1.360 (4)	1.239 (3)	Moschellandsbergite	102
2.35 (9)	1.228 (6)	2.04 (5)	Silver	134
2.36 (9)	2.04 (6)	1.23 (5)	Gold	69
2.40 (7)	5.20 (6)	3.11 (6)	Sulvanite	143
2.425 (4)	2.665 (1)	1.81 (1)	Löllingite	93
2.43 (3)	1.82 (2)	2.82 (1)	Arsenopyrite	12
2.45 (8)	2.72 (5)	1.82 (4)	Glaucodot	67
2.46 (5)	2.13 (1)	1.51 (.5)	Cuprite	47
2.48 (8)	2.32 (8)	1.87 (2)	Tenorite	148
2.51 (5)	2.84 (1)	2.23 (1)	Delafossite	51
2.53 (5)	1.475 (2)	2.96 (1)	Magnetite	95
2.53 (6)	1.715 (6)	2.31 (5)	Gersdorffite	66
2.55 (7)	1.49 (4)	1.62 (2)	Franklinite	60
2.55 (6)	1.71 (5)	2.33 (4)	Corynite	43
2.55 (8)	2.86 (3)	2.37 (2)	Pararammelsbergite	121
2.59 (4)	2.83 (3)	2.43 (3)	Argentite	9
2.61 (7)	1.845 (4)	1.502 (1)	Alabandite	3
2.60 (10)	2.37 (4)	1.635 (4)	Safflorite	127
2.60 (4)	2.84 (3)	2.44 (3)	Jalpaite (copper bearing argentite)	
2.60 (5)	3.62 (4)	3.15 (4)	Berthierite	16
2.62 (5)	2.40 (2)	1.78 (1)	Kallilite	84
2.62 (6)	2.40 (3)	1.77 (2)	Willyamite	159
2.62 (5)	3.65 (4)	3.18 (3)	Berthierite	
2.64 (10)	1.86 (3)	1.62 (3)	Skutterudite	135
2.64 (9)	1.87 (4)	2.22 (3)	Smaltite-chloanthite	34

TABLE 2. INDEX OF POWDER PATTERNS—*Continued*

Strongest Lines and their Relative Intensities			Name	Pattern Number (In Table 1)
1	2	3		
2.64 (6)	1.95 (5)	1.795 (3)	Niccolite	106
2.64 (8)	2.41 (3)	1.78 (3)	Ullmanite	154
2.68 (6)	2.45 (5)	1.81 (4)	Penroseite	109
2.69 (9)	1.65 (6)	1.415 (3)	Braunite	24
2.69 (7)	1.68 (5)	2.51 (4)	Hematite	78
2.70 (6)	3.80 (4)	1.755 (2)	Bournonite	
2.715 (6)	1.762 (4)	3.47 (3)	Marcasite	96
2.72 (10)	2.035 (9)	1.73 (7)	Maucherite	97
2.72 (2)	2.53 (2)	2.025 (2)	Ilmenite	81
2.72 (4)	3.85 (3)	1.77 (2)	Seligmannite	131
2.73 (2)	2.30 (2)	2.11 (1)	Baumhauerite	14
2.74 (8)	1.867 (6)	2.04 (5)	Arsenic	11
2.74 (5)	3.90 (1)	1.765 (1)	Bournonite	22
2.77 (4)	1.675 (3)	2.49 (2)	Bravoite	23
2.77 (5)	1.85 (4)	2.50 (3)	Millerite	103
2.77 (3)	1.97 (1)	3.20 (.5)	Cerargyrite	30
2.77 (6)	2.11 (3)	2.03 (3)	Petzite	111
2.77 (4)	2.37 (2)	2.28 (2)	Hauchecornite	167
2.79 (7)	2.55 (6)	3.20 (5)	Pyrargyrite	116
2.80 (3)	3.68 (2)	2.00 (1)	Boulangerite	21
2.81 (4)	2.47 (3)	2.94 (2)	Polybasite	113
2.81 (4)	2.01 (3)	2.49 (2)	Cobaltite	39
2.82 (6)	1.68 (5)	2.38 (2)	Linnaeite	91
2.82 (8)	1.93 (4)	2.075 (3)	Melonite	98
2.82 (4)	2.44 (3)	1.99 (2)	Aguilarite	1
2.82 (5)	3.22 (1)	3.41 (1)	Aramayoite	
2.82 (5)	3.28 (4)	3.42 (3)	Schapbachite	129
2.83 (8)	3.02 (7)	2.09 (4)	Nagyagite	105
2.84 (5)	1.661 (3)	2.35 (2)	Violarite	
2.84 (1)	3.00 (.5)	3.09 (.3)	Pearceite	108
2.84 (3)	3.21 (3)	1.85 (2)	Enargite	
2.84 (10)	3.24 (5)	3.43 (4)	Aramayoite	8
2.85 (2)	1.67 (2)	2.36 (1)	Siegenite	133
2.85 (6)	1.67 (5)	2.47 (4)	Carrollite	28
2.85 (5)	2.05 (2)	1.97 (2)	Breithauptite	25
2.85 (8)	3.22 (7)	1.855 (5)	Enargite	
2.85 (9)	3.34 (9)	1.68 (4)	Cinnabar	36
2.85 (3)	3.48 (2)	2.01 (2)	Benjaminite	15
2.86 (8)	1.678 (7)	2.37 (3)	Violarite	156
2.86 (3)	3.55 (2)	3.38 (2)	Kobellite	88
2.87 (7)	1.67 (6)	2.37 (4)	Polydymite	114
2.87 (6)	2.30 (6)	2.24 (5)	Hessite	79
2.88 (5)	3.42 (4)	2.74 (3)	Miargyrite	101

TABLE 2. INDEX OF POWDER PATTERNS—*Continued*

Strongest Lines and their Relative Intensities			Name	Pattern Number (In Table 1)
1	2	3		
2.88 (5)	3.43 (3)	2.06 (2)	Franckeite	59
2.89 (4)	2.03 (1)	1.81 (1)	Cylindrite	49
2.90 (4)	3.24 (3)	2.74 (2)	Meneghinite	99
2.917 (4)	2.46 (2)	2.18 (2)	Wolframite	162
2.94 (8)	4.71 (4)	1.71 (4)	Ferberite	58
2.95 (9)	1.81 (6)	1.541 (6)	Tennantite	147
2.95 (4)	3.40 (2)	2.02 (2)	Cosalite	44
2.96 (8)	1.81 (6)	1.54 (5)	Tetrahedrite	150
2.96 (6)	2.08 (5)	1.785 (5)	Galena	63
2.96 (2)	2.72 (2)	2.32 (1)	Rathite	122
2.96 (3)	2.79 (3)	2.47 (1)	Stromeyerite	142
2.965 (8)	4.83 (6)	3.77 (5)	Hübnerite	80
2.99 (5)	3.75 (3)	3.45 (2)	Livingstonite	92
2.99 (5)	2.09 (4)	1.77 (1)	Calaverite	26
3.00 (10)	1.72 (4)	1.45 (3)	Columbite-tantalite	40
3.00 (10)	1.83 (7)	1.56 (5)	Schirmerite	130
3.01 (4)	2.84 (3)	2.09 (2)	Dufrenoyite	53
3.02 (6)	1.77 (6)	2.50 (3)	Daubreelite	50
3.03 (7)	1.86 (4)	1.59 (1)	Chalcopyrite	32
3.035 (3)	2.715 (1)	2.49 (1)	Hauerite	76
3.05 (8)	2.12 (6)	2.96 (3)	Sylvanite	144
3.05 (8)	2.12 (5)	2.95 (3)	Krennerite	89
3.05 (3)	2.68 (2)	2.45 (1)	Argyrodite	10
3.06 (10)	1.87 (8)	1.59 (4)	Famatinite (luzonite)	57
3.06 (9)	2.165 (7)	1.370 (4)	Clausthalite	37
3.06 (4)	2.56 (3)	2.90 (2)	Stephanite	139
3.06 (8)	3.20 (7)	2.34 (3)	Emplectite	55
3.07 (8)	1.875 (4)	1.60 (2)	Germanite	65
3.07 (7)	1.88 (5)	1.601 (3)	Colusite	41
3.07 (6)	2.13 (2)	2.23 (2)	Antimony	7
3.08 (10)	1.89 (7)	1.61 (5)	Famatinite (luzonite)	
3.08 (6)	1.89 (4)	1.613 (3)	Cu, Fe, S	166
3.09 (6)	2.91 (4)	2.57 (4)	Stephanite	
3.10 (9)	2.13 (3)	2.25 (2)	Grunlingite and Oruetite	73
3.11 (10)	1.625 (6)	2.41 (5)	Pyrolusite	118
3.11 (8)	1.91 (5)	1.63 (2)	Stannite	138
3.12 (9)	1.78 (3)	2.32 (2)	Wittichenite	160
3.12 (6)	1.91 (5)	1.63 (4)	Sphalerite	137
3.12 (4)	2.06 (3)	1.89 (3)	Greenockite	72
3.12 (8)	2.12 (3)	2.30 (2)	Tetradymite	149
3.13 (8)	2.99 (8)	1.76 (4)	Chalcostibite	33
3.14 (5)	2.92 (4)	2.70 (3)	Kermesite	85
3.16 (10)	2.31 (5)	2.17 (5)	Bi, S, Te	165
3.17 (10)	1.64 (5)	2.00 (4)	Wulfenite	161
3.17 (2)	2.99 (2)	2.85 (1)	Samsonite	126

TABLE 2. INDEX OF POWDER PATTERNS—*Continued*

Strongest Lines and their Relative Intensities			Name	Pattern Number (In Table 1)
1	2	3		
3.17 (8)	3.62 (8)	2.86 (7)	Aikinite	2
3.18 (3)	2.22 (2)	1.82 (2)	Guitermanite	75
3.20 (9)	2.36 (4)	2.18 (4)	Von Diestite	168
3.20 (10)	2.37 (8)	2.19 (8)	Tellurobismuthite	146
3.20 (6)	2.53 (4)	2.75 (2)	Proustite	115
3.20 (7)	3.08 (8)	2.34 (3)	Emplectite	55
3.21 (3)	1.435 (3)	2.245 (2)	Bismuth	18
3.21 (8)	2.85 (8)	1.86 (7)	Enargite	56
3.22 (9)	2.33 (4)	2.22 (3)	Tellurium	145
3.22 (6)	2.35 (3)	2.21 (3)	Wehrlite	158
3.22 (4)	2.67 (2)	1.64 (2)	Cuprodescloizite	48
3.22 (3)	3.01 (3)	3.60 (2)	Rezbanyite	124
3.23 (5)	1.875 (4)	1.75 (3)	Cubanite	46
3.23 (1)	3.82 (.5)	3.38 (.5)	Fuloppite	62
3.25 (8)	2.00 (8)	2.90 (7)	Klockmannite	87
3.28 (5)	2.80 (4)	2.04 (2)	Diaphorite	52
3.28 (4)	2.90 (3)	2.75 (2)	Andorite, Ramdohrite	6
3.28 (5)	3.00 (3)	2.74 (1)	Semseyite	132
3.30 (9)	2.40 (2)	2.20 (2)	Wehrlite	
3.32 (6)	2.62 (6)	1.75 (6)	Cassiterite	29
3.34 (9)	2.85 (9)	1.68 (4)	Cinnabar	36
3.35 (5)	2.88 (4)	2.08 (2)	Schaphbachite	129
3.36 (10)	2.07 (5)	1.77 (5)	Metacinnabar	100
3.38 (10)	2.10 (8)	1.79 (8)	Tiemannite	151
3.40 (10)	2.06 (3)	1.68 (2)	Graphite	71
3.40 (3)	2.81 (2)	2.72 (2)	Jamesonite	82
3.42 (4)	2.78 (3)	1.99 (1)	Plagionite	112
3.45 (5)	2.82 (5)	2.96 (2)	Freieslebenite	61
3.48 (3)	2.95 (2)	2.76 (2)	Sartorite	128
3.50 (9)	3.08 (6)	1.935 (5)	Bismuthinite	19
3.55 (6)	1.94 (4)	1.69 (4)	Stibnite	141
3.57 (5)	2.85 (3)	2.95 (2)	Lorandite	94
3.60 (6)	3.15 (6)	1.83 (4)	Umangite	155
3.61 (9)	3.16 (8)	2.86 (4)	Guanajuatite	74
3.62 (8)	3.17 (8)	2.86 (7)	Aikinite	2
3.80 (3)	3.00 (3)	2.03 (3)	Cannizarite	27
3.80 (5)	3.47 (5)	2.94 (3)	Gratonite	70
4.17 (9)	2.46 (4)	1.73 (3)	Goethite	68
4.25 (6)	3.25 (3)	2.79 (3)	Sternbergite	140
4.57 (4)	2.85 (3.5)	3.07 (3)	Klaprotholite	86
4.80 (6)	2.82 (3)	2.70 (3)	Orpiment	107
5.2 (6)	2.40 (7)	3.11 (6)	Sulvanite	143
5.4 (3)	3.15 (3)	2.93 (3)	Realgar	123
6.2 (9)	2.68 (6)	2.28 (2)	Tungstenite	153

FURTHER STUDIES OF THE LEPIDOLITE SYSTEM

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About ten years ago the writer made his third attempt¹ to correlate the chemical composition and optic properties of the lithia micas. At that time he wrote: "An attempt to solve this problem (the formulas of these micas) has met with little success," and "some examples do not agree well with the diagram. Apparently these micas are dimorphous, and that condition would doubtless entail variations in optical properties, the extent and character of which are at present unknown." Since then he has continued work on the problem and has obtained the kind cooperation of several colleagues who have generously supplied samples from various localities, in some cases, of analyzed material. It is a pleasure to acknowledge the assistance of Dr. Harry Berman of Harvard University, Dr. W. F. Foshag of the United States National Museum, Miss Jewell Glass, Dr. W. T. Schaller, and Dr. R. E. Stevens of the U. S. Geological Survey, Edward S. Simpson, Government Mineralogist of Western Australia, Dr. C. H. Stockwell of the Geological Survey of Canada, and H. Gordon Taylor of Boston, Mass.

In order to eliminate the possibility of confusion on account of including more than one crystal phase in the study, all available samples were studied by x-ray methods to determine the crystal symmetry; some samples were analyzed, and many were measured optically. This work was made possible by generous grants from the Wisconsin Alumni Research Foundation, continued for three years. In this work the author has had the efficient assistance of E. J. Lyons, R. G. Comer, J. J. Marais, John J. Ronan, B. E. Steierman and Sturges W. Bailey.

The following new analyses of lithia micas have been made for this study. Analyses 10*a*, 17*a*, 24*a* and 26*a* are included from the literature for comparison.

Two recent studies of lithia micas are of much importance. R. E. Stevens² published seventeen new analyses of lithia micas and discussed their interpretation. He found that the old analyses of polyolithionite were inaccurate and a new analysis leads to $K_2Li_4Al_2Si_8O_{20}F_4$ as the correct formula of this end-member of the lepidolite system. This confirms the conclusion of Mauguin that lithia micas have 24 negative (O+F,OH) ions in the crystals and that they are like biotite (and unlike muscovite) in containing sixteen positive ions. The lithia micas are accordingly octophyllites, but, nevertheless, they seem to intercrystallize with biotite

¹ Winchell, A. N., *Am. Mineral.*, **17**, 551 (1932).

² Stevens, R. E., *Am. Mineral.*, **23**, 607 (1938).

TABLE 1

Sample No.	10	10a	17	17a	18	24	24a	26	26a
SiO ₂	49.19	49.58	49.14	51.11	50.16	46.74	45.23	51.88	50.31
TiO ₂	0.08	0.06	0.00		0.00	0.00	n.d.	0.21	0.22
Al ₂ O ₃	24.81	23.87	27.66	25.26	23.54	21.78	21.78	20.65	19.95
Fe ₂ O ₃	0.24	0.21	0.43	0.20	0.46	1.19	0.47	0.79	0.99
FeO				0.07	1.27	10.22	11.25	1.99	2.55
MnO	2.51	2.78	1.22	0.17	0.79	0.37	1.73	2.01	2.63
MgO	0.05	0.00	0.05	0.01	0.06	0.00	0.23	0.00	0.02
CaO	tr.	0.00	tr.	0.12	0.04	0.00	n.d.	0.00	tr.
Li ₂ O	5.10	5.05	3.95	4.98	5.34	3.72	3.23	5.26	5.39
Na ₂ O	0.52	0.57	0.40	1.43	1.10	0.54	0.78	0.51	0.59
K ₂ O	10.25	10.14	10.13	10.51	10.97	10.37	9.98	10.55	10.14
Rb ₂ O	1.78	1.62	1.17	n.d.	n.d.	n.d.	n.d.	n.d.	0.97
Cs ₂ O	0.19	0.09	0.62	n.d.	n.d.	n.d.	n.d.	n.d.	0.06
H ₂ O—	1.21	n.d.	n.d.	n.d.	0.78	n.d.	n.d.	n.d.	n.d.
H ₂ O+		1.22	2.64	0.94	1.39	0.89	0.97	1.89	0.88
F	6.89	7.49	5.21	6.57	6.75	7.54	7.98	7.65	7.65
Cl	n.d.	n.d.	n.d.	n.d.	0.05	n.d.	n.d.	n.d.	n.d.
	102.82	103.19	102.62	103.11	102.70	103.36	103.63	103.39	102.51
O=F	2.90	3.15	2.19	2.76	2.85	3.17	3.35	3.22	3.22
	99.92	100.04	100.43	100.35	99.85	100.19	100.28	100.17	99.29

10. Lepidolite, Ohio City, Colorado. R. B. Ellestad, analyst. U. S. Nat. Mus. No 97893.

10a. Lepidolite, Ohio City, Colorado. R. E. Stevens, analyst, *Am. Mineral.*, **23**, 607 (1938). U. S. Nat. Mus. No. 97893.

17. Lepidolite, Mt. Apatite, Auburn, Maine. R. B. Ellestad, analyst, U. S. Nat. Mus. No. 80230.

17a. Lepidolite, Auburn, Maine. R. B. Riggs, analyst. *U. S. Geol. Surv., Bull.* **42**, 17 (1887).

18. Lepidolite, Alabashta, Urals. F. A. Gonyer, analyst.

24. Zinnwaldite, Zinnwald, Erzgebirge. F. A. Gonyer, analyst.

24a. Zinnwaldite, Zinnwald, Erzgebirge, W. Kunitz: *N. Jahrb. Mineral., Bl. Bd.*, **50**, 365 (1924).

26. Zinnwaldite, Wakefield, Quebec. F. A. Gonyer, analyst.

26a. Zinnwaldite, Wakefield, Quebec. R. E. Stevens: *Am. Mineral.*, **23**, 607 (1938).

little, if at all. Being octophyllites, they do not intercrystallize with the heptaphyllite micas (the muscovite system), just as is to be expected, although they are frequently closely associated with muscovite—perhaps even interleaved with it in some cases.

A second paper of great importance in regard to lithia micas was published very recently by Hendricks and Jefferson.³ They show that micas

³ Polymorphism of the micas: *Am. Mineral.*, **24**, 729 (1939).

are not only dimorphous, but polymorphous, there being one hexagonal, four monoclinic and two triclinic phases. They find evidence that a small amount of lithia (at most probably about 3%), can enter the muscovite structure, but this produces a lithium-bearing muscovite and not a member of the lepidolite system. Only three structures have been found in that system, namely the three layer hexagonal (uniaxial), the single layer monoclinic hemihedral and the six layer monoclinic hemihedral. But the optical properties of some lithia micas make it probable that they can also take on either the six or the twenty-four layer triclinic structure.

In attempting to solve the problem of the composition of the end members of the lepidolite system it is important, first, to select the best analyses of the lithia micas, and, second, to eliminate those which are lithium-bearing muscovites, or biotites, rather than true members of the lepidolite system. There seems to be no infallible method to select the best analyses, but it is probably prudent to omit all those more than twenty years old and also certain others which seem incomplete or unsatisfactory. Stevens' excellent analyses include one (No. 1) which Hendricks and Jefferson have proved to be a lithium-bearing muscovite and four (Nos. 2-5) which certainly are not lepidolites. Omitting these, the analyses of most importance for the purpose may be listed as follows:

1. Lepidolite, Epprechtstein, Fichtelgebirge. W. Kunitz: *N. Jahrb. Mineral., Bl. Bd.* **50**, 365 (1942). Kunitz No. 3.
2. Lepidolite, Penig-Chursdorf. W. Kunitz: *loc. cit.*
3. Lepidolite, Penig-Auersdorf. W. Kunitz: *loc. cit.*
4. Lepidolite, Indiakawa, Mursinsk. W. Kunitz: *loc. cit.*
5. Lepidolite, Rozna, Moravia. J. Sekanina and J. Vyslonzil: *Mineral. Abst.*, **4**, 379 (1930).
6. Lepidolite, Stewart mine, Pala, California. R. E. Stevens: *Am. Mineral.*, **23**, 607 (1938). Stevens No. 6.
7. Lepidolite, Ohio City, Colorado. R. E. Stevens: *loc. cit.* No. 7.
8. Lepidolite, Himalaya mine, Mesa Grande, California. R. E. Stevens: *loc. cit.* No. 8.
9. Lepidolite, San Diego mine, Mesa Grande, California. R. E. Stevens: *loc. cit.* No. 9.
10. Lepidolite, Ohio City, Colorado. R. B. Ellestad., analyst. See Table 1.
11. Lepidolite, Stewart mine. Pala, California. R. E. Stevens: *loc. cit.* No. 11.
12. Lepidolite, Stewart mine, Pala, California. R. E. Stevens: *loc. cit.* No. 12.
13. Lepidolite, Himalaya mine, Mesa Grande, California. R. E. Stevens: *loc. cit.* No. 13.
14. Lepidolite, Calgoorlie, W. Australia. R. E. Stevens: *loc. cit.* No. 14.
15. Lepidolite, Little Three mine, Ramona, California. R. E. Stevens: *loc. cit.* No. 15.
16. Lepidolite, Antsongombato, Madagascar. R. E. Stevens: *loc. cit.* No. 16.
17. Lepidolite, Mt. Apatite, Maine. R. B. Ellestad, analyst. See Table 1.
18. Lepidolite, Alabaschta, Urals. F. A. Gonyer, analyst. See Table 1.
19. Polyolithionite, Kangarluarsuk, Greenland. R. E. Stevens: *loc. cit.* No. 17.
20. Protolithionite, Zinnwald, Erzgebirge. W. Kunitz: *loc. cit.* No. 8 (p. 413) and No. 11 (pp. 394, 395).
21. Zinnwaldite, Altenberg, Erzgebirge. W. Kunitz: *loc. cit.* No. 7 (p. 413) and No. 10 (pp. 394, 395).

22. Zinnwaldite, Zinnwald, Erzgebirge. W. Kunitz: *loc. cit.* No. 6 (p. 413) and No. 9 (pp. 394., 395).
23. Zinnwaldite, Schlaggenwald, Bohemia. W. Kunitz: *loc. cit.* No. 5 (p. 413) and No. 8 (pp. 394, 395).
24. Zinnwaldite, Zinnwald, Erzgebirge. F. A. Gonyer, analyst. See Table 1.
25. Zinnwaldite, Wakefield, Quebec. R. E. Stevens; *loc. cit.* No. 10.
26. Zinnwaldite, Wakefield, Quebec. F. A. Gonyer, analyst. See Table 1.
27. Zinnwaldite, Morefield mine, Amelia, Virginia. J. J. Glass: *Am. Mineral.*, **20**, 741 (1935).
28. Taeniolite, Magnet Cove, Arkansas. H. D. Miser and R. E. Stevens: *Am. Mineral.*, **23**, 104 (1938).

With the formula of one end-member (polyolithionite) of the lepidolite system now well established as $K_2Li_4Al_2Si_8O_{20}F_4$, the formulas of other end-members can be written with somewhat less uncertainty. The lithia micas are now known to be octophyllites, that is, they have eight positive ions for twelve negative ions; therefore formulas like $K_4Li_6Al_6Si_{15}O_{40}F_8$ are unsatisfactory. $K_4Li_7Al_7Si_{14}O_{40}F_8$ is correct, but it is not an end-member, since it gives neither maximum nor minimum tenor of any element. So far as known $K_2Li_3Al_5Si_6O_{20}F_4$ represents the minimum tenor of Li for lepidolites containing no divalent atoms, and $K_2LiFe_4Al_3Si_6O_{20}F_4$ (protolithionite) seems to represent the maximum tenor of divalent atoms together with minimum tenor of lithium. The second end-member ($K_2Li_3Al_5Si_6O_{20}F_4$) has no name and no varietal name in the literature seems to be appropriate. In these circumstances the writer would suggest that it be called paucilithionite.

Including the new analyses of Stevens, more than two dozen high grade analyses of lithia micas are now available (see Table 1). If they are calculated into the end-members named above (see Table 2) a surprising result is obtained: Li_2O is deficient in all cases (except one) and the average deficiency is almost one per cent by weight (0.91). This result demands an explanation. It seems that it must be due to one (or more) of the following causes:

1. The formulas of the end-members are incorrect. At first thought this seems to be the most probable explanation. However, Stevens' analysis of polyolithionite is the only one that shows no deficiency in lithia and therefore that formula seems to be incontestable. With the known structure of micas in mind and the requirement of eight positive ions for each twelve negative ions a reduction in lithium below the tenor shown in $K_2Li_3Al_5Si_6O_{20}F_4$ (assuming no other elements present) leads to the formula $K_2Li_2Al_8Si_4O_{20}F_4$.

This formula requires decidedly more alumina and less silica than are found in any mica, and, moreover, if it is used as an end member with $K_2Li_4Al_2Si_8O_{20}F_4$ computation of analyses so as to use all the silica and

TABLE 2. DISCREPANCIES IN SELECTED ANALYSES OF LITHIA MICAS
Assuming as end-members: $K_2Li_4Al_2Si_8O_{20}F_4$, $K_2Li_3Al_5Si_6O_{20}F_4$ and $K_2LiFe_4Al_3Si_6O_{20}F_4$

Analysis No.	Li ₂ O		K ₂ O+Na ₂ O+Rb ₂ O+Cs ₂ O		(F, OH)		Remarks
	Rel. Mol.	Weight %	Rel. Mol.	Weight %	Rel. Mol.	Weight %	
1	- 29	- .87	+10	+ .94	+ 84	+ 1.60	Explanation of Table 2. The relative numbers of molecules (Rel. Mol.) are obtained by dividing each weight percentage of each analysis by its molecular weight, multiplied by one thousand to avoid decimals, and then making as many as possible of each end-member using all the silica and alumina. With F, H ₂ O+ is included (as 2 OH) in all cases and H ₂ O- is included (as 2 OH) in the calculations of Nos. 8, 10, 13, 14, 17, and 27. The weight percentage of K ₂ O+Na ₂ O+Rb ₂ O+Cs ₂ O is obtained by assuming that the deficiency or excess is solely K ₂ O. Similarly (F, OH) is assumed to be F for this calculation.
2	- 51	- 1.53	+10	+ .94	- 24	- .45	
3	- 58	- 1.74	+16	+1.50	- 26	- .49	
4	- 33	- .99	+13	+1.22	+ 8	+ .15	
5	- 31	- .93	+11	+1.03	- 4	- .08	
6	- 52	- 1.56	- 4	- .38	+ 14	+ .27	
7	- 26	- .78	+ 2	+ .19	+ 40	+ .76	
8	- 56	- 1.68	-11	-1.03	- 14	- .27	
9	- 36	- 1.08	+ 7	+ .66	+ 42	+ .80	
10	- 25	- .75	+ 3	+ .28	+ 2	+ .04	
11	- 12	- .36	0	0	+ 12	+ .23	
12	- 29	- .87	0	0	+ 44	+ .84	
13	- 19	- .57	0	0	- 2	- .04	
14	- 13	- .39	0	0	- 10	- .19	
15	- 11	- .33	+ 3	+ .28	+ 40	+ .76	
16	- 1	- .03	+ 2	+ .19	+ 30	+ .57	
17	- 66	- 1.98	- 5	- .47	+ 60	+ 1.14	
18	- 22	- .66	+ 2	+ .19	+ 14	+ .27	
19	+ 4	+ .12	- 1	- .09	- 34	- .65	
20	- 25	- .75	+ 6	+ .56	+ 48	+ .91	
21	- 34	- 1.02	+ 8	+ .75	+ 38	+ .72	
22	- 34	- 1.02	0	0	+ 32	+ .61	
23	- 28	- .84	+ 5	+ .47	+ 88	+ 1.67	
24	- 30	- .90	0	0	+ 20	+ .38	
25	- 10	- .30	+ 1	+ .09	+ 18	+ .34	
26	- 24	- .72	- 4	- .38	+118	+ 2.24	
27	- 69	- 2.07	+ 2	+ .19	- 22	- .42	
	-820	-24.60	+76	+7.13	+616	+11.71	
Average	- 30.4	- 0.91	+ 2.8	+ .264	+ 22.7	+ .43	

alumina shows that the deficiency in lithia remains unchanged. It seems reasonable to conclude that this method of reducing the lithium required by the formulas is not correct.

2. In spite of the great inequality in the atomic domains is it possible that potassium may proxy for lithium to a limited extent? This explanation is clearly unsatisfactory, since the average number of atoms of potassium apparently available is less than one-tenth of the number needed

to supply the average deficiency of lithium, and the excess of potassium does not increase with the deficiency of lithium; on the contrary two of the analyses with the largest deficiencies of lithium (No. 6 and 8) are also deficient in potassium.

3. It is doubtless quite unnecessary to point out that fluorine cannot proxy for lithium since these ions have opposite electric charges. However, even if this were possible, it would not solve the problem since the average excess of fluorine (22.7 ions) is only about one-third the average deficiency of lithium (60.8 ions).

4. Can the deficiency in lithia be due to errors in the chemical analyses? The quantitative determination of Li_2O is not easy and some old analyses are clearly inaccurate, but the careful analyses of recent years are unquestionably good and it is doubtful whether even one-tenth of the average deficiency actually found can be reasonably ascribed to errors.

5. Can the deficiency in lithia be due to impure samples? It is only necessary to read the description of the precautions used by Stevens to ensure the purity of his samples to reach the conclusion that any impurities (in the ordinary sense) in his samples were far less than necessary to explain the deficiency in lithia. It is true that the average deficiency in lithia (0.66 weight %) in his analyses is less than the average found in others, but two of his analyses show deficiencies exceeded only rarely in other analyses, so that his precautions failed to eliminate the main cause of the difficulty.

6. Can the deficiency in lithia be due to another end-member of an isomorphous system, not replacing, but supplementing, those already used? It seems to be difficult, if not impossible, to prove or to disprove this hypothesis, but the writer has failed to discover another end-member which has eight positive ions for twelve negative ions and will eliminate the lithia deficiency without introducing other important discrepancies. Apparently no such a thing exists.

7. Can the deficiency in lithia be explained by assuming the presence of some heptaphyllite mica such as muscovite, $\text{H}_2\text{KAl}_3\text{Si}_3\text{O}_{12}$, containing only seven positive ions for twelve negative ions? The results of this assumption are shown in Table 3.

It appears that this assumption suffices to eliminate the deficiency in lithia in all cases (in one case it is cut down from -69 only to -3) without introducing any other inconsistencies except for the fact that the average excess of K_2O molecules is increased from 2.8 to 4.1, and the average excess of F ions is increased from 22.7 to 27.3. However, the average excess of K_2O in the twelve analyses of Stevens is only 0.6, an amount probably within the limits of accuracy that can be expected. And, since Stevens has proved that Rb_2O and Cs_2O are normal constituents of lithia micas, it is evident that analyses in which these elements are included

TABLE 3. DISCREPANCIES IN SELECTED ANALYSES OF LITHIA MICAS ASSUMING SOME MUSCOVITE, $H_2KAl_3Si_3O_{12}$, PRESENT WITH $K_2Li_4Al_2Si_3O_{20}F_4$, $K_2Li_3Al_3Si_6O_{20}F_4$ AND $K_2LiFe_4Al_3Si_6O_{20}F_4$

Analysis No.	$K_2O + Na_2O + Rb_2O + Cs_2O$		F, OH		Mol. % $H_2KAl_3Si_3O_{12}$	Remarks
	Rel. Mol.	Weight %	Rel. Mol.	Weight %	(Muscovite)	
1	+ 12	+ 1.13	+ 90	+ 1.71	16.0	After the calculations for Table 2 it is necessary merely to compute from the original analysis two-thirds as many muscovite molecules as the number of lithia deficiency molecules in order to eliminate this deficiency—though the percentages of the lithia end-members do not remain unchanged. (In 27 the deficiency can be reduced from 69 to 3, but not to 0.)
2	+ 12	+ 1.13	— 14	— .27	27.5	
3	+ 20	+ 1.88	— 10	— .19	31.7	
4	+ 15	+ 1.41	+ 14	+ .27	17.8	
5	+ 7	+ .66	— 22	— .42	15.4	
6	— 2	— .19	+ 16	+ .30	27.2	
7	+ 2	+ .19	+ 38	+ .72	14.6	
8	— 8	— .75	— 1	— .02	29.9	
9	+ 1	+ .09	+ 20	+ .38	18.2	
10	+ 3	+ .28	+ 6	+ .11	13.0	
11	+ 3	+ .28	+ 13	+ .25	6.6	
12	+ 1	+ .09	+ 48	+ .91	16.0	
13	— 3	— .28	+ 10	+ .19	9.3	
14	+ 1	+ .09	— 6	— .11	6.6	
15	+ 4	+ .38	+ 41	+ .78	6.5	
16	+ 2	+ .19	+ 31	+ .59	0.8	
17	— 3	— .28	+ 68	+ 1.29	34.4	
18	+ 13	+ 1.22	+ 62	+ 1.18	11.4	
19	— 1	— .09	— 34	— .65	0.0	
20	+ 7	+ .66	+ 52	+ .99	15.0	
21	+ 10	+ .94	+ 46	+ .87	19.3	
22	+ 2	+ .19	+ 42	+ .80	18.9	
23	+ 7	+ .66	+ 72	+ 1.37	15.4	
24	+ 1	+ .09	+ 25	+ .48	17.0	
25	+ 2	+ .19	+ 22	+ .42	5.8	
26	— 3	— .28	+ 121	+ 2.30	13.0	
27	+ 7	+ .66	— 12	— .23	37.7	
	+ 112	+ 10.53	+ 738	+ 14.02	445.0	
Average	+ 4.1	+ 0.39	+ 27.3	+ 0.32	16.5	

with K_2O must show an apparent excess of that oxide. In fact, if the percentages of Rb_2O and Cs_2O determined by Stevens are assumed to be K_2O his analyses will then show an apparent excess of K_2O very similar to (though even greater than) the average excess found in the other analyses. Since water is included with fluorine, and water is notoriously difficult to determine accurately, the increase in the average excess of this constituent from 22.7 to 27.3 ions does not seem important.

Accordingly, it seems that all the best analyses of lithia micas can be explained satisfactorily in terms of these four molecules. However, the writer accepts only three of these as end-members of the lepidolite system and considers that the muscovite molecule enters into crystal solution in this system only very little, if at all. The reasons for this view need careful and full statement.

1. Theoretically, it seems improbable that a crystal structure containing eight positive ions for twelve negative ions can change *gradually* into one containing seven positive ions for twelve negative ions. One can get a mental picture of the problem by trying to imagine a *gradual* change from the structure shown in Hendricks and Jefferson's⁴ Fig. 1a to that shown in their Fig. 1b. Or, assuming that the structure remains that of Fig. 1a, how can the eight ions of that figure change *gradually* into the seven ions of Fig. 1b? It seems probable the layer of ions having octohedral coordination must be uniform—either the one pattern or the other.

2. Actually it is well known to every student of rocks that muscovite and biotite often exist side by side. If heptaphyllites and octophyllites can intercrystallize to form one substance their existence side by side should be rare and due to formation at different times. Actually it is very common and there is every reason to think that the two minerals formed at the same time, at least in many cases.

3. Analyses of micas show only rare and doubtful cases that are supposed by some writers to represent types intermediate between muscovite and biotite. A sample of "alurgite" from California has been described⁵ as such a type, but the evidence does not seem conclusive to the writer nor to Schaller.⁶

4. Lepidolite and muscovite are also often closely associated. Such a condition is described by many writers including Scherizer,⁷ Baumhauer,⁸ Bowman,⁹ Stockwell,¹⁰ and Kunitz.¹¹ In some cases they are described as formed at the same time; in other cases they have zonal arrangement showing formation at different times. If they can intercrystallize to form one substance they should never form simultaneously side by side. An especially good illustration of this condition is furnished by Stevens who writes: "The lepidolite samples were furnished by Dr. Schaller, of the

⁴ *Am. Mineral.*, **24**, 131 (1939).

⁵ Webb, R. W., *Am. Mineral.*, **24**, 123 (1939)

⁶ *Am. Mineral.*, **24**, 127 (1939).

⁷ *Zeits. Kryst.*, **12**, 5 (1886); **13**, 22, 464 (1887).

⁸ *Zeits. Kryst.*, **51**, 344 (1912).

⁹ *Mineral. Mag.*, **13**, 97 (1902).

¹⁰ *Trans. Roy. Soc. Canada*, **27**, 27 (1933).

¹¹ *Chemie der Erde*, **4**, 231 (1930).

U. S. Geological Survey, who examined them optically to be sure that no impurities were present which could not be easily removed. Five samples were discarded because the small flakes of lepidolite were found to contain numerous minute inclusions of muscovite . . . This occurrence of minute inclusions of muscovite in lepidolite is apparently not unusual."

It is the writer's theory that such intergrowths of muscovite and lepidolite are very common and of all sizes from those which are apparent in museum-size crystals, through those observed by Schaller microscopically to units which are too small to be seen microscopically, but nevertheless are quite different in character from crystal solution, since they are *two* substances, whereas crystal solution of two (or more) end-members leads to *one* substance. The writer¹² demonstrated some years ago that quartz may exist as an aggregate of units which are too small to be seen with a microscope and so small that many exist in the thickness of a thin section and, being in random position, compensate each other in birefringence effects so that the aggregate is isotropic. Moreover, by chance the quartz units at a given point in the thin section may be dominantly in or near one orientation and then that point will show very weak birefringence. Similarly, the units of muscovite and lepidolite may be in entirely irregular positions, but are probably in most cases more or less parallel, especially as to the vertical axes, so that the basal cleavages are parallel. Thus a cleavage plate, apparently from one single crystal, may actually contain both minerals in submicroscopic intergrowth, but not at all in crystal solution.

Unfortunately this conception must be presented as a theory whose validity the writer is unable to demonstrate at the present time. However, various facts tend to support the theory.

1. It is known that muscovite and lepidolite form aggregates (with parallel cleavages) when both micas are in large units (*e.g.*, one or more centimeters across). It is likewise known that they form aggregates when one or both are in small units—units which are easily visible microscopically, but probably *about* one-hundredth of a millimeter in diameter since they are described as "minute." That is, the known range in size is from about 10 mm. to about .01 mm. If the range of size actually extends downward a tenth again as much as is known, it would be quite sufficient for the theory.

2. The common existence of these minerals side by side suggests that they cannot intercrystallize to form one substance.

3. A similar condition of a mineral in submicroscopic units has been proved to exist in quartz.

¹² Winchell, A. N., *Am. Mineral.*, **9**, 235 (1924).

4. If muscovite and lepidolite actually intercrystallize to form one substance that substance should have optical properties which are the same in all parts of a crystal, or any single mass of crystals formed at the same time (assuming no zonal growth to be present). On the other hand, if muscovite and lepidolite form interleaved aggregates it is to be expected that they would be present in variable proportions so that optical properties would vary in different parts of a crystal or mass of crystals. The results of careful measurements of refractive indices of lithia mica samples from various localities are assembled in Table 4.

TABLE 4. MEASURED PROPERTIES OF LITHIA MICAS

No.	Calc. % Musc.	G	N _g	N _m	N _p	N _g -N _p	2V	Measured by
1	16.0	2.820	1.5563	1.5525	1.5295	0.0268	46°6'	W. Kunitz: <i>Neues Jahrb. Min. Bl. Bd. 50</i> , 365 (1924)
2	27.5							
3	31.7	2.837	1.5617	1.5574	1.5329	0.0288	43°46'	W. Kunitz: <i>loc. cit.</i>
4	17.8	2.881	1.5661	1.5626	1.5371	0.0291	40°28'	W. Kunitz: <i>loc. cit.</i>
5	15.4	2.832		1.558			39°	J. Sekanina: <i>Min. Abst.</i> , 4, 379
6	27.2		1.560 ¹				25-30°	M. E. Jefferson: <i>Am. Mineral.</i> , 24, 729
6	27.2		1.5581	1.5553	1.5307 calc.	0.0274	37.2°	J. J. Marais ²
7	14.6		1.562				25-40°	M. E. Jefferson: <i>loc. cit.</i>
7	14.6		1.5668	1.5635	1.5398	0.0270	36.8°	J. J. Marais
7	14.6		1.5630	1.5616	1.5480 calc.	0.0150	35°	J. J. Ronan ²
7	14.6		1.5632	1.5600	1.5292 calc.	0.0340	35°	J. J. Ronan
7	14.6		1.5636	1.5612	1.5262 calc.	0.0275	35°	J. J. Ronan
8	21.8		1.56				30-40°	M. E. Jefferson: <i>loc. cit.</i>
8	21.8		1.5633	1.5575	1.5356	0.0277	50.5°	J. J. Marais
8	21.8		1.5582	1.5561			34°	J. J. Marais
			-1.5599	-1.5568				
8	21.8		1.5607	1.5578	1.5452 calc.	0.0175	47°	J. J. Ronan
8	21.8		1.5611	1.5568	1.5381 calc.	0.0230	50°	J. J. Ronan
8	21.8		1.5634	1.5582	1.5409 calc.	0.0225	50°	J. J. Ronan
8	21.8		1.5634	1.5593	1.5414 calc.	0.0220	49°	J. J. Ronan
9	18.2		1.555				55-58°	M. E. Jefferson: <i>loc. cit.</i>
9	18.2		1.5577	1.5530	1.5331	0.0246	52.5°	J. J. Marais
9	18.2		1.5590	1.5552	1.5336	0.0254	50.2°	J. J. Marais
9	18.2		1.5591	1.5540	1.5318	0.0273	50.6°	J. J. Marais
10	13.0		1.5647	1.5627	1.5335	0.0292	35°	R. G. Comer ²
10	13.0		1.5668	1.5635	1.5398	0.0270	36.8°	J. J. Marais
10	13.0		1.5620	1.5586	1.5315 calc.	0.0305	38°	J. J. Ronan
10	13.0		1.5620	1.5598	1.5398 calc.	0.0222	36°	J. J. Ronan
11	6.6							R. E. Stevens: <i>Am. Mineral.</i> , 23, 607
12	16.0		1.554				35°	M. E. Jefferson: <i>loc. cit.</i>
12	16.0		1.5567	1.5545	1.5344	0.0233	35°	J. J. Marais
13	9.3		1.558				25-30°	M. E. Jefferson: <i>loc. cit.</i>
13	9.3		1.5590	1.5542	1.5330	0.0260	56°	J. J. Marais
13	9.3		1.5591	1.5568	1.5372	0.0219	30.6°	J. J. Marais
13	9.3		1.5594	1.5547	1.5356	0.0238	46.2°	J. J. Marais
13	9.3		1.5603	1.5554	1.5333	0.0270	50°	J. J. Marais
14	6.6		1.558	1.558	1.535	0.033	0°	M. E. Jefferson: <i>loc. cit.</i>
14	6.6		1.5546	1.5546	1.5324	0.0222	0°	J. J. Marais
			-1.5556	-1.5556	-1.5334	-0.0234		
15	6.5		1.555	1.5515	1.533	0.022	45°	M. E. Jefferson: <i>loc. cit.</i>
15	6.5		1.5546	1.5519	1.5315	0.0232	45°	R. G. Comer

TABLE 4. MEASURED PROPERTIES OF LITHIA MICAS—*Continued*

No.	Calc. % Musc.	G	N _g	N _m	N _p	N _g -N _p	2V	Measured by
15	6.5		1.5546	1.5518	1.5318	0.0228	46.5°	J. J. Marais
15	6.5		1.5556	1.5522	1.5325	0.0231	44.2°	J. J. Marais
15	6.5		1.5542	1.5512	1.5452 calc.	0.0190	46°	J. J. Ronan
16	0.8		1.5562	1.5522	1.5318	0.0244	45.5°	Wunder and Sabot ³
16	0.8		1.558					M. E. Jefferson: <i>loc. cit.</i>
16	0.8		1.5540	1.5508	1.5345	0.0195	48.2°	J. J. Marais
16	0.8		1.5555	1.5528	1.5346	0.0209	49.3°	J. J. Marais
16	0.8		1.5571	1.5537	1.5343	0.0228	48.2°	J. J. Marais
16	0.8		1.5574	1.5537	1.5334	0.0240	48.3°	J. J. Marais
17	34.4		1.5863	1.5804	1.5516	0.0347	45°	R. G. Comer
17	34.4		1.5584	1.5565	1.5330	0.0254	32°	J. J. Marais
17	34.4		1.5604	1.5588	1.5430 calc.	0.0174	36°	J. J. Marais
17	34.4		1.5624	1.5594	1.5332	0.0292	43°	J. J. Marais
18	11.4		1.5574	1.5540	1.5325	0.0249	45.6°	J. J. Marais
18	11.4		1.5577	1.5562	1.5390	0.0187	32°	J. J. Marais
18	11.4		1.5581	1.5547	1.5314	0.0267	45.6°	J. J. Marais
18	11.4		1.5607	1.5564	1.5310	0.0297	46.5°	J. J. Marais
19	0.0	2.81 ⁴	1.569				40°	M. E. Jefferson: <i>loc. cit.</i>
19	0.0		1.5640	1.5607	1.5404	0.0235	43.6°	J. J. Marais
19	0.0		1.5648	1.5634	1.5465	0.0183	38.2°	J. J. Marais
19	0.0		1.5660	1.5636	1.5441	0.0219	38.8°	J. J. Marais
19	0.0		1.5692	1.5673	1.5541	0.0151	38°	J. J. Marais
19	0.0		1.5620	1.5596	1.5380 calc.	0.0240	36°	J. J. Ronan
19	0.0		1.5634	1.5595	1.5253 calc.	0.0381	37°	J. J. Ronan
19	0.0		1.5650	1.5616	1.5350 calc.	0.0300	39°	J. J. Ronan
19	0.0		1.5670	1.5638	1.5430 calc.	0.0240	42°	J. J. Ronan
19	0.0		1.5673	1.5640	1.5375 calc.	0.0298	39°	J. J. Ronan
19	0.0		1.5674	1.5642	1.5383 calc.	0.0291	38°	J. J. Ronan
19	0.0		1.5678	1.5631	1.5362 calc.	0.0316	44°	J. J. Ronan
19	0.0		1.5708	1.5672	1.5482 calc.	0.0226	46°	J. J. Ronan
19	0.0		1.5736	1.5686	1.5631 calc.	0.0375	42°	J. J. Ronan
20	15.0	3.148	1.6057	1.6057	1.5724 calc.	0.0333	0°	W. Kunitz: <i>loc. cit.</i>
21	19.3	3.018	1.5876	1.5850	1.5572	0.0304	20.7°	W. Kunitz: <i>loc. cit.</i>
22	18.9	2.987	1.5812	1.5777	1.5511	0.0301	29.6°	W. Kunitz: <i>loc. cit.</i>
23	15.4	2.97	1.5792	1.5754	1.5485	0.0307	31.3°	W. Kunitz: <i>loc. cit.</i>
24	17.0		1.5750	1.5729	1.5435	0.0315	32°	R. G. Comer
24	17.0		1.5757	1.5737	1.5450	0.0307	30°	R. G. Comer
25	5.8		1.562				30°	M. E. Jefferson: <i>loc. cit.</i>
			1.5628	1.5596	1.5357	0.0271	39°	R. G. Comer
			1.5674	1.5637	1.5440	0.0234	38°	R. G. Comer
26	13.0		1.5701	1.5671	1.5415	0.0286	34°	J. J. Marais
27	37.7		1.580	1.580	1.550	0.030	0-33°	J. J. Glass
			-1.590	-1.590	-1.558	-0.032		
27	37.7		1.5770	1.5754	1.5463	0.0307	28°	R. G. Comer
27	37.7		1.5781	1.5762	1.5424	0.0357	30°	R. G. Comer
27	37.7		1.5783	1.5760	1.5400	0.0383	30.4°	J. J. Marais
27	37.7		1.5784	1.5767	1.5488	0.0296	30.1°	J. J. Marais
27	37.7		1.5786	1.5762	1.5450	0.0336	30.4°	J. J. Marais
28	0.0		1.553	1.553	1.522	0.031	0°±	Miser and Stevens: <i>Am. Mineral.</i> , 23, 104 (1938)

¹ Corrected from 1.550 in personal communication from M. E. Jefferson, June 3, 1940.² Measures by Marais, Ronan and Comer were made by universal stage immersion methods at the University of Wisconsin.³ *Mem. Soc. Phys. Hist. Nat. Genève*, 36, 367 (1910).⁴ Lorenzen: *Zeits. Kryst.*, 7, 610 and 9, 251.

In Table 4 the most accurate measures are those for N_g (and N_m in some cases). As made at the University of Wisconsin by Comer and by Marais using the double variation method with the five axis universal stage, these measures are believed to be accurate within ± 0.0005 . Now the measures on a single sample (and even on a single tiny flake in some cases) made by the same person differ as much as several times this amount, reaching ten times as much in sample 19. Miss Glass reports a variation of .01 in sample 27, but the accuracy of her measures is not reported. If the measures of the same sample (that is, from the same source and in some cases from the same large U. S. National Museum sample) made by different persons be compared, the differences are still greater, being .005 in sample 19, .006 in sample 7, .0081 in samples 25, 26, .013 in sample 27, and .0279 in sample 17. It is therefore well established that a single sample varies considerably in optical properties. And it is also well established that such a variation is found in so many of the samples that it may be said to be the usual condition.

When it is remembered that the lowest value for N_g measured on any lithia mica is 1.554 while N_g in muscovite is 1.588, it is readily seen that 5 to 35 per cent of muscovite interleaved with lithia mica will not raise the index a great deal. In fact, 5 per cent would raise the index from 1.554 to 1.5557, 15 per cent would raise it to 1.5597, and even 35 per cent would raise it only to 1.5659. Irregularities in the distribution of the muscovite may be expected to be ordinarily no more than a minor fraction of the per cent present. Accordingly, the differences in index due to this cause should be commonly a minor fraction of the increases just noted, that is, less than half of: .0017 for 5 per cent, .0051 for 15 per cent, .0085 for 25 per cent, and .0119 for 35 per cent. The differences actually observed are of this order of magnitude. The fact that sample 19 with no calculated muscovite shows similar differences may be regarded as an exception, but this may be explained on the ground that the analysis does not represent the same material that was studied optically, just as the two analyses (25 and 26) of lithia mica from the same source (Wakefield, Quebec) are not exactly alike, but one requires the assumption of twice as much muscovite as the other.

As previously noted, zonal and other coarse intergrowths of muscovite and lepidolite have been described many times, and minute intergrowths were found in five samples by Schaller, but there is evidence which suggests that such intergrowths are much commoner than indicated by these reports. It is usually assumed that the two minerals can be distinguished by their colors, but this is often not true as shown by the fact that samples carefully selected for chemical analysis and study of the lithia micas have been shown in several cases to be muscovites, in some instances almost

completely devoid of lithia. The writer has had this experience and it is indicated in the writings of Stockwell and others. Pink and purple muscovites have been described by Schaller¹³ and green muscovite by Stockwell. It seems probable that the same influences which cause the color of lithia mica may cause similar color in muscovite; if that be true, then muscovite intergrown with lepidolite is much more likely to be colored like it than is muscovite not closely associated with lithia mica. Again, Comer's measures of the optical properties of "lepidolite" from Mt. Apatite, Maine, indicate that he measured those of a flake of muscovite, though the measures of Marais and also the analysis prove that the sample is largely lepidolite. If the theory of the writer as to the correct interpretation of the analyses of lithia micas be accepted, then the analyses themselves prove either an isomorphous system or an intergrowth of two minerals in nearly all cases.

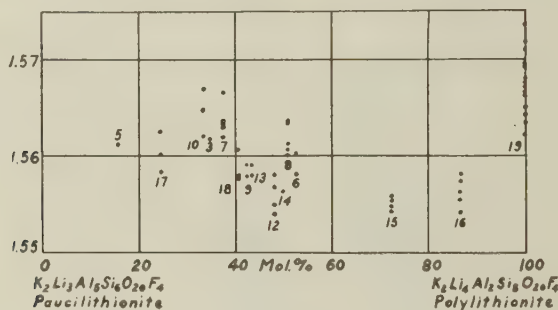


FIG. 1

It is desirable next to study the relations between variations in composition and in optical properties. These can be seen much more clearly by dealing with the binary series, and we may begin with the paucilithionite-polyolithionite series ($K_2Li_3Al_6Si_6O_{20}F_4$ - $K_2Li_4Al_2Si_8O_{20}F_4$). The first nineteen analyses belong to this series, but samples 2 and 11 were not measured optically and sample 4 contains about 16 per cent of protolithionite and is therefore omitted. The others¹⁴ are shown in Fig. 1 as calculated into these two molecules, disregarding the deficiencies in Li_2O , and also the protolithionite, which is less than 10 per cent in all cases and averages only 4.8. Samples 1, 3, and 5 appear at only one point each on the diagram, probably not because they do not vary, but because only one measure was made (or, at least, only one reported). The value of

¹³ *Am. Mineral.*, 11, 5 (1926).

¹⁴ The value, 1.5863 for N_g measured by Comer on sample 17 is not included in the figure since it is considered to be evidence of nearly pure muscovite.

N_g for sample 5 was calculated from $N_m = 1.558$ and $2E = 63^\circ$ (as reported), assuming $N_g - N_p = 0.025$, which is an approximation for lepidolite. It is obvious that this diagram leads to no satisfactory correlation. The only safe conclusions are that in ordinary lepidolite $N_g = 1.56 \pm 0.01$ and that the index varies very little from paucilithionite to polyolithionite.

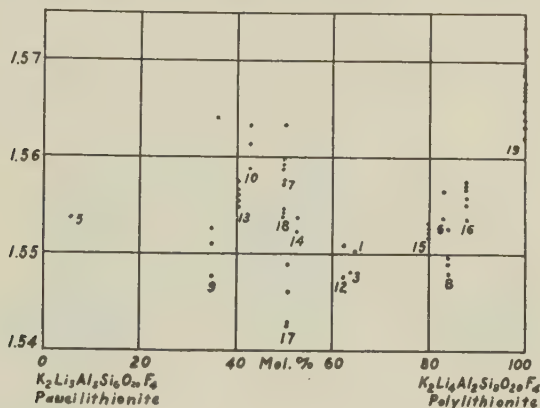


FIG. 2

However, study of the chemical analyses has led to the theory that lithia micas commonly contain variable amounts of muscovite in an intimate intergrowth with lepidolite proper. If sufficient muscovite be subtracted from each analysis to eliminate the deficiency of lithia and the remainder be calculated into the three lithia mica end-members, the percentages of these (for paucilithionite and polyolithionite) are not the same as at first computed because these percentages depend upon the ratios of Al_2O_3 to SiO_2 and these ratios are changed by subtracting muscovite. It is obvious that there is no way to know whether the flake used to determine the optic properties contained the same proportion of muscovite as the material analyzed. If it be assumed that such was the case, it is possible to calculate the index of refraction (N_g) necessary in the lithia mica to give the measured index in the aggregate. The results of plotting the indices (N_g) thus derived against the computed percentage of polyolithionite (disregarding protolithionite, as was done before) are shown in Fig. 2. It is evident that the correlation is even worse than in Fig. 1. This result suggests that (as might have been expected) the flake used to determine the index did not contain the same proportion of muscovite as the mass that was analyzed. In some large units it is known that lithia mica is surrounded by muscovite, or vice versa, when viewed in a cleavage piece. If this condition is common, any small flake used to measure

the index is probably much more nearly muscovite-free than is an aggregate used for chemical analysis. Accordingly, it is desirable to plot the percentage of polylithionite as corrected for muscovite against the indices (N_g) as measured. The results are shown in Fig. 3.

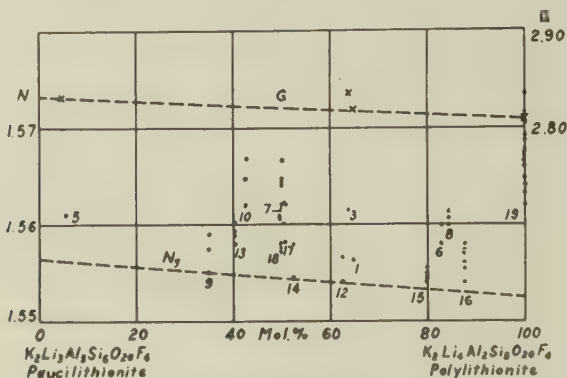
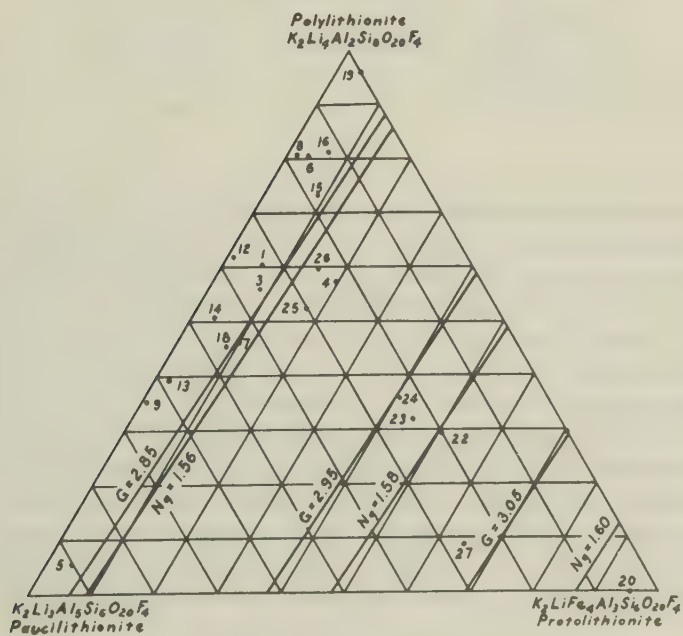
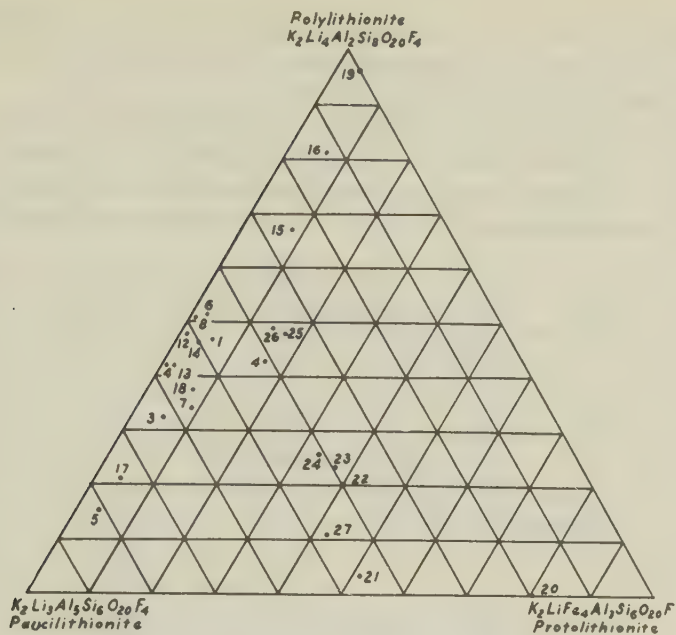


FIG. 3

It is clear that any mixture of the paucilithionite-polyolithionite series ($N_g = 1.56 +$) with muscovite ($N_g = 1.588$) will have an index higher than the muscovite-free mineral. Therefore, in any such mixture (presumably irregular) the fragment with the lowest index has the least admixed muscovite. It may be reasonable to assume that the lowest values in the diagram were obtained from fragments containing no muscovite. If so, N_g in all kinds of lepidolite containing no protolithionite is nearly equal to 1.555. It is perhaps significant that the five samples (9, 12, 14, 15, 16) which are almost on the minimum line have an average muscovite tenor of 9.6 while the remaining eleven samples have nearly twice as much (18.3), even though they include one (19) the analysis of which indicates that it contains no muscovite at all. Furthermore, samples 15 and 16 are reasonably slightly above the line because they contain a little protolithionite.

Many measures were made on samples available to determine the amount of variation in optical properties, since that may serve as a measure of their variability in composition. The results as shown in Table 4 prove that these lithia micas vary in properties very much more than is known in most minerals, and, in all cases measured, the variation is toward muscovite. In one case (No. 17) one measure gave results which indicate pure muscovite. Sample 19—the polyolithionite from Greenland—varies in index (N_g) more than any other sample (disregarding the approximate figures of Glass on sample No. 27) except for one measure on



sample 17, just cited. Therefore the sample analyzed from Greenland seems to have been unlike the sample from the same place which is available for measures of the optical properties.

Before studying another binary series it is desirable to get a picture of the ternary system: paucilithionite-polyolithionite-protolithionite. If the analyses are calculated into these three formulas, disregarding deficiencies in lithia, and plotted on a triangle, the results are shown in Fig. 4. But it

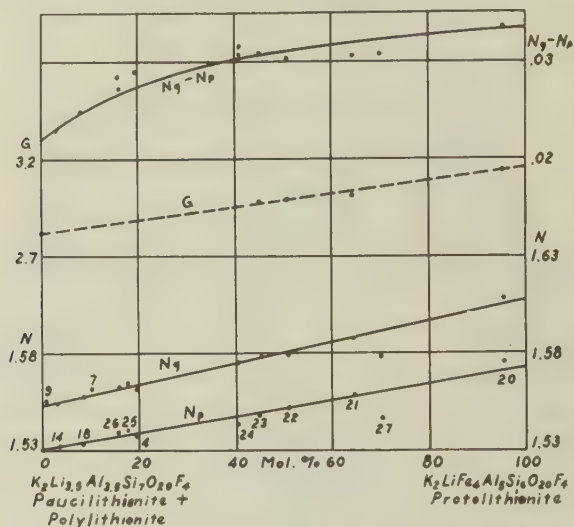


FIG. 6

seems probable that muscovite is present in most of the samples analyzed; if the analyses are recalculated, after eliminating the indicated muscovite, the diagram resulting is shown in Fig. 5. Since the variations in properties in the paucilithionite-polyolithionite series are slight, they may be disregarded, and all samples with an appreciable tenor of protolithionite may be considered to belong to a series from 50 paucilithionite-50 polyolithionite to pure protolithionite as shown in Fig. 6. From these two binary series the properties of the ternary system may be approximated by extrapolation, as shown by the lines in Fig. 5. Unfortunately, these lines indicate the properties in muscovite-free lithia micas, and lithia micas usually contain admixed muscovite, according to the theory proposed in this paper. The writer is unable to present a diagram which includes this molecule; it would seem to require the use of a tetrahedron.

CONDITIONS FOR THE FORMATION OF PARAGONITE

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ABSTRACTS

It is possible to synthesize paragonite hydrothermally in acid solutions. X-ray powder photographs confirm these results. Reasons for the scarcity of paragonite are advanced.

There has been considerable discussion, especially lately,¹ with regard to the validity of paragonite as a species. A number of analyses are now available that seem to leave little doubt that soda micas actually exist. On the other hand, there have been no x-ray structure data on paragonite.

It occurred to the writer to synthesize the mineral by the same method he had used to obtain muscovite.² The gold-lined bomb used for these experiments has been described a number of times. The bomb has a volume of 50 cc. In each of the two experiments it was filled with 20 cc. of N/0.103 HCl solution. The air above the solution was displaced by CO₂ at atmospheric pressure and room temperature. The other constituents of the bomb were:

318 mg. Al(OH)₃ = artificial bayerite containing 37% H₂O.

270 mg. "Silicic acid." It contains 10.36% H₂O = approx. SiO₂ · $\frac{1}{2}$ H₂O.

2000 mg. NaCl, analytical grade.

The ratio of Al(OH)₃:SiO₂ · $\frac{1}{2}$ H₂O was equivalent to Al₂O₃:SiO₂ in paragonite. The amounts theoretically were sufficient to produce 500 mg. of paragonite. The temperature was 400° ± 5° C. and the length of the experiment was 7 days.

The product was carefully boiled with distilled water several times after removal from the bomb, dried on a steam radiator and x-rayed. Unfiltered Fe radiation was used. The camera had a radius of 57.3 mm. Very good negatives were obtained. These resemble natural and synthetic muscovite, but there are distinct differences in spacings. The planar-spacings together with those of synthetic muscovite are listed in Table 1. The intensities of the natural and synthetic products are quite different for the basal plane reflections due to the preferred orientation of the cleavage particles of natural muscovite. The particles of synthetic micas are so small that such preferred alignment does not occur in mounting the powders. The theoretical intensities of the basal reflections were com-

¹ McCormick, R. B., Paragonite from Pizzo Forno, Ticino, Switzerland: *Am. Mineral.*, **19**, 431-432 (1934).

Schaller, W. T., and Stevens, R. E., The validity of paragonite as a mineral species: *Am. Mineral.*, **26**, 541-545 (1941).

² Gruner, J. W., Formation and stability of muscovite in acid solutions at elevated temperatures: *Am. Mineral.*, **24**, 524-528 (1939).

puted for paragonite and compared with the observed ones. The agreement is as good as can be expected in powder photographs.

TABLE 1. PLANAR SPACINGS AND RELATIVE INTENSITIES OF SYNTHETIC
PARAGONITE AND SYNTHETIC MUSCOVITE
Unfiltered Fe K radiation. Camera radius 57.3 mm.

PARAGONITE			MUSCOVITE		
Spacing	Intensity	Indices	Spacing	Intensity	Indices
9.79	5	002	10.09	6	002
4.81	2	020 β	4.86	2	020 β
4.42	8	020	4.44	7	020
4.24	0.5		3.898	1	
3.515	3	006 β	3.649	2	006 β
3.352	0.5				
3.204	8	006	3.339	6	006
3.052	2		3.118	1	
2.798	3	β	2.822	2	β
2.677	1		2.708	1	
2.533	8		2.560	6	
2.417	3	008	2.471	2	008
			2.370	2	
2.215	0.5		2.239	2	
2.168	1				
2.092	2		2.138	2	
2.043	0.5				
1.934	2	0010	2.016	1	0010
			1.974	1	
1.855	2		1.872	1	
1.776	0.5				
1.676	1		1.703	1	
1.643	2	060 β	1.653	2	
1.605	1				
1.559	0.5				
1.488	7	060	1.501	5	060

Mention must be made that some boehmite $\text{AlO}(\text{OH})$ had also been produced in the experiments. Its two strongest lines, which do not coincide with any of paragonite, could easily be observed. These occur at 6.04 Å and 2.34 Å. Boehmite is a frequent product in the writer's hydrothermal experiments, but it is also the most abundant aluminum hydroxide in some bauxites. It may be pointed out at this place that x-ray powder diffraction lines of boehmite as recorded recently³ by Mehmel,

³ Mehmel, Martin, Datensammlung zum Mineralbestimmen mit Röntgenstrahlen: *Fortsch. Min., Krist. und Petr.*, **23**, 103 (1939).

and supposed to be used for identification of minerals, are not the lines of boehmite but of some substance unknown to the writer.

Why boehmite should have formed with the paragonite in the experiments mentioned is a question not readily answered, unless boehmite is an intermediate product and would disappear after equilibrium was reached. There is one other possibility. Considerable amounts of the silica present might be prevented from forming paragonite by the large excess of sodium in the solution. The aluminum hydroxide remaining might form boehmite. About 0.1 g. of the sample was analyzed for Na_2O by Dr. R. B. Ellestad. The percentage was 5.4 as compared with 8.11 for theoretically pure paragonite. At least a part of this deficiency can be ascribed to the admixture of boehmite. If this is done this synthetic material probably contains at least as much Na_2O as some natural paragonites reported by Schaller and Stevens.⁴

One wonders why paragonite is relatively uncommon in nature. Perhaps this scarcity is only apparent since paragonite cannot be distinguished from muscovite by its optical properties. There certainly seems to be no lack of sodium in many places where muscovite has formed. Among the numerous analyses of mica one would expect more soda mica, if the scarcity of paragonite were not real.

Then the question naturally arises, why are potassium micas so much more abundant. There seem to exist about three to four times as many species of silicates containing sodium as silicates with potassium. This preponderance may be caused by the small size of the sodium ion (0.96 Å) compared with the potassium ion (1.33 Å). A large cation, potassium, needs a much larger space and for this reason must surround itself with more oxygen ions to form a stable structure. In other words, it will have a coordination of 10 to 12. Such positions in natural silicates are uncommon except in a few "open" structures as in mica, feldspar and leucite. On the other hand, the smaller sodium cation usually has only 6 to 8 coordinates, or bonds, and fits into a more compact structure of SiO_4 or AlO_4 tetrahedra. This coordination permits a far greater variety of stable structures. Also sodium, due to its similar size, does replace calcium, and more rarely, magnesium in a number of silicates.

For this very reason, however, sodium ions enter potassium positions in the mica structure only under very special conditions, for here they must occupy positions which are evidently too large and possess, therefore, too weak and too many bonds. In the iron and magnesium micas, sodium ions in potassium positions are even more scarce on account of the still larger spacings in the structure. Lithium being much smaller than

⁴ *Op. cit.*, p. 544.

sodium occupies aluminum positions, the potassium positions being barred to it. One of the special conditions under which paragonite can form is that of the experiments described. In neutral or basic solutions of similar experiments the author did not produce paragonite, but nepheline or unidentified products.

CONCLUSIONS

Paragonite mica was produced synthetically in N/.10 HCl solutions at 400° C. X-ray powder photographs show that the spacing of the unit cell normal to (001) is $19.33 \pm 0.02 \text{ \AA}$, compared with 20.0 \AA in muscovite. The width (b_0) of paragonite is $8.90 \pm .02 \text{ \AA}$ and of muscovite $9.00 \pm .02 \text{ \AA}$. It is thought that paragonite is uncommon because sodium ions are so small that they will not fit readily into the potassium positions of the micas. They prefer positions with 6 to 8 bonds to the potassium positions which have twelve, unless no other positions are available. In HCl solutions the aluminum micas seem to be the only alkali-bearing silicates which are comparatively stable, and for this reason sodium mica can form. It must not be concluded, however, that paragonite could form only in acid solutions.

DOLOMITE PSEUDOMORPHOUS AFTER CRYSTALS OF ARAGONITE*

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Geological Survey, U. S. Department of the Interior, Washington, D. C.

ABSTRACT

The flat hexagonal crystals from the Big Horn Basin, Wyoming, locally called "Indian Pennies," are shown to consist of dolomite pseudomorphous after crystals of aragonite.

INTRODUCTION

Dolomitization of rock calcite (as limestone) is a common geologic phenomenon. Hewett,¹ for example, has called attention to its widespread occurrence.

Pseudomorphs of dolomite after crystals of calcite (that is, as a mineral) seem to be very rare. Hintze² lists only a single recorded example, although a long list of other minerals have been recorded as pseudomorphs after calcite. Pseudomorphs of other minerals after aragonite likewise are rare. Hintze³ lists only calcite (paramorphs), copper, and deweylite, although the silica pseudomorphs of quartz or chalcedony after aragonite, found along the Canadian River in Oklahoma, have long been known. Pseudomorphs of dolomite after aragonite, though not listed by Hintze, were described by Breithaupt⁴ in 1863. He describes a crystal of aragonite four inches long and one-half an inch thick, from Kolosoruk near Bilin, Bohemia, which has changed to dolomite with less than the normal quantity of magnesia. The pseudomorphous crystal is built up of small rhombohedra of dolomite in various orientations. Cornu⁵ in 1904 described parallel fibered aragonite, filling cavities in the basalt of the Bohemian Mittelgebirge, which has changed to yellowish-white dolomite. His analysis: 34.09 CaO, 18.11 MgO, 0.90 FeO, 47.30 CO₂, gangue 0.06, with traces of SrO and Al₂O₃, total 100.46, indicates the presence of a slight excess of CaCO₃. The change is ascribed to the effects of meteoric water containing magnesium bicarbonate in solution.

Dolomite pseudomorphous after aragonite occurs in abundance in

* Published by permission of the Director, U. S. Geological Survey.

¹ Hewett, D. F., *Geology and ore deposits of the Goodsprings Quadrangle, Nevada: U. S. Geol. Survey, Prof. Paper 162*, 57-67 (1931); Dolomitization and ore deposition: *Econ. Geology*, **23**, 821-863 (1928).

² Hintze, Carl, *Handbuch der Mineralogie*, Band 1, Abt. 3:1, p. 2893 (1930).

³ *Op. cit.*, pp. 2985-2986.

⁴ Breithaupt, August, *Pseudomorphosen, Berg-und Huellenmaennische Zeitung*, Band 22, 118 (1863).

⁵ Cornu, F., *Pseudomorphose von Dolomit nach Aragonit: Tschermak's mineralog. und petrogr. Mitteil.*, Band 23, 217-218 (1904).

Wyoming. The occurrence is well known but it seems not to have been recognized that the flat hexagonal crystals are now dolomite. The occurrence was recently described.⁶

OCCURRENCE AND DISTRIBUTION

During the course of geologic investigation of the northeast side of the Big Horn Basin of Wyoming and Montana, from 1935 through 1939, D. A. Andrews collected numerous flat tabular pseudohexagonal crystals to which his attention had been directed by residents of the area who called them "Indian Pennies", although no record of their tribal or ceremonial use by the Crow Indians who occupied this area can be found.⁷

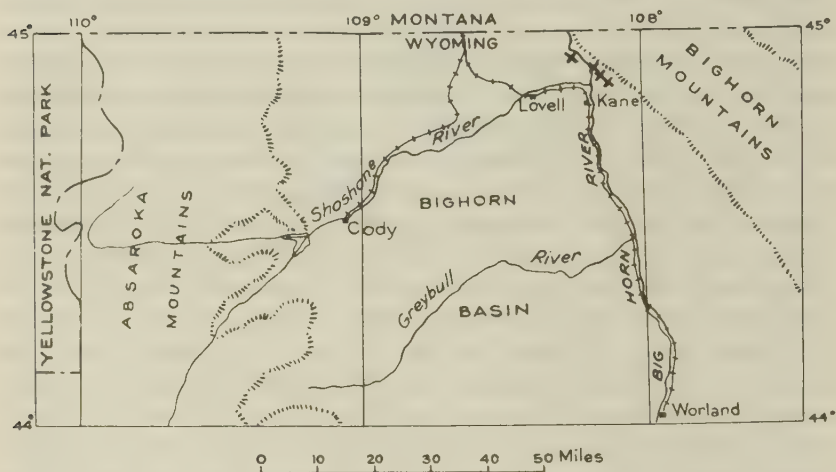


FIG. 1. Location of dolomite pseudomorphs after aragonite.

These crystals were found near the Big Horn River where it enters the Big Horn Canyon across the northern end of the Big Horn Mountains. The locality (Fig. 1) is easily reached by car from Lovell, Wyoming, by following the paved road eastward from Lovell to Kane, then northward four miles and northwest three miles to the locality. The crystals occur near the base of the red beds on the south side of a saddle between two small gravel terraces 300 feet above the river. This locality is about one-half mile south of the Abercambie dredge and quarry. Other localities can be visited by continuing eastward from Kane on the paved highway one and one-half miles across the Big Horn River, then following the

⁶ Goldring, E. D., Aragonite crystals from Wyoming: *The Mineralogist (Oregon)*, **9**, 16 (1941).

⁷ Lowie, R. H., *The Crow Indians*. Farrar and Rinehart, New York (1935).

well marked trail northeastward along a gravel slope three miles to the foot of the mountain slope where the base of the red beds is exposed, and following this horizon northwestward toward the Big Horn River.

The crystals are found in a bed of gypsum at the base of the Chugwater formation and directly on top of the uppermost limestone of the Embar formation. The red beds of the Chugwater type interfinger with the gray cherty limestones of the Embar formation, and the contact between the two formations is here arbitrarily drawn at the top of the uppermost limestone. Some of the red beds in central Wyoming are Triassic in age but most of the limestones in this part of the Big Horn Basin have yielded fossils of Permian age. The red beds at this locality are 600 feet thick.

The crystals are embedded in the upper part of this gypsum bed. Because of surficial changes of structure in the gypsum bed it is difficult to ascertain the exact position or occurrence in the bed itself. They are usually found in the upper few inches of the gypsum bed, but it cannot be stated positively that they are not present throughout the gypsum bed. In one place the crystals were lying flat roughly one on top of another forming a stack of eight or ten crystals much like a stack of poker chips.

Structurally the beds in this vicinity are dipping southwest along the western flanks of the Big Horn Mountains. This area is north of the major uplift and here the Big Horns rise in a series of three monoclines with dips of 20° to 25° common on the steeper portions of the monoclines, flattening abruptly to less than 5° on the more gentle portions. About 10 miles to the southeast the Big Horns rise abruptly from the Basin in one slope with dips up to 90° .

Aragonite is commonly associated with gypsum deposits so that its presence here requires no explanation. The unusual feature is the replacement of the aragonite by dolomite. If the gypsum were deposited by evaporation of normal marine waters a source of magnesium might be expected in the salts last deposited by such waters. Two arguments can be readily advanced against this source. First, none of the gypsum in the Big Horn Basin, either in the overlying Chugwater formation or in the underlying Embar formation, has been reported to be associated with any other salts.⁸ Secondly, if the magnesium salts gave rise to the solutions producing the replacement why has not this replacement been reported more commonly because aragonite and magnesium sulphate are in common occurrence with gypsum. It seems far more likely that the replacement is due to the same factors that produced extensive dolomiti-

⁸ Lupton, C. T., and Condit, D. D., Gypsum in the southern part of the Big Horn Mountains, Wyoming: *U. S. Geol. Survey, Bull.* **640**, 139-157 (1916).

zation of the limestones in the underlying Carboniferous formations along and adjacent to the Big Horn Mountains.

DESCRIPTION OF PSEUDOMORPHS

The flat hexagonal crystals, a group of which is shown in $\frac{1}{2}$ natural size in Fig. 2, range in size from about one to two inches across, averaging about an inch and a half. They are rather uniformly about a quarter of

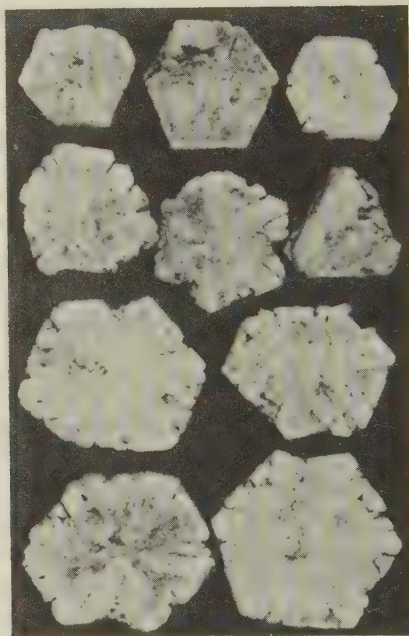


FIG. 2. Dolomite pseudomorphous after crystals of aragonite. $\frac{1}{2}$ Natural size.

an inch thick. In color they range from nearly white through light gray to light brown where slightly stained by iron oxide. They have a dull luster, and are pitted with small holes and with lines following the crystallographic directions of the original aragonite. Inspection with a hand lens readily shows that the crystals are now composed of many small crystallographic units, variously oriented and closely compacted. Lining some of the small pits are individual rhombohedra not sharply outlined.

Some of the crystals, as shown in the top row of Fig. 2, are framed by a narrow border of the same material, slightly lighter in color and more compact. A thin section, parallel to the base, shows the heterogeneous orientation of the individual grains of dolomite, as shown in Fig. 3.

The shape of the crystals, the indentations around the border, and the markings on the base, are all typical of the common twinned crystals of aragonite of this tabular habit. Only one crystal (shown in Fig. 2) out of about a hundred collected shows a symmetrical trigonal development but this is believed to be very unusual for the occurrence.

Small areas of fine-grained gypsum are scattered irregularly through the pseudomorphous crystals, as seen in thin section. On the basis of the percentage of SO_3 , the gypsum amounts to about two per cent.

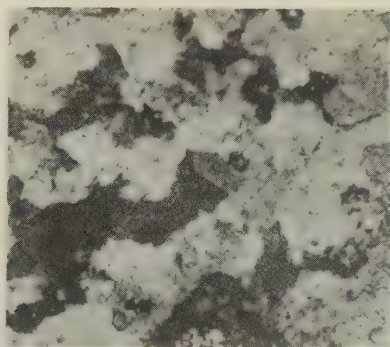


FIG. 3. Thin section, parallel to the base, of a pseudomorph, showing the heterogeneous orientation of the individual grains of dolomite. Nicols crossed. $\times 48$.

Tested by the staining method, using ferric chloride and ammonium sulphide, as described by Sherman and Thiel,⁹ the crushed material remained white (as does dolomite and magnesite) whereas aragonite and calcite stain black. There were a few isolated small black areas in the material tested which may be residual aragonite but more probably are enclosed gypsum. Tests with various forms of gypsum showed that this mineral is not stained black but all the samples of gypsum tested showed a few small black areas, probably due to some ferric chloride entering minute cleavage openings and not being washed out before the fragments were treated with ammonium sulphide.

The material does not effervesce with cold 1:1 HCl and the ω index of refraction is 1.680. Analysis of part of one of the crystals gave the following results:

⁹ Sherman, G. D., and Thiel, G. A., Dolomitization in glacio-lacustrine silts of Lake Agassiz; *Bull. Geol. Soc. Am.*, **50**, 1540 (1939).

ANALYSIS OF DOLOMITE PSEUDOMORPHOUS AFTER ARAGONITE

[W. T. Schaller, analyst]

CaO	30.60
MgO	21.12
CO ₂ ^a	45.65
SO ₃	0.98
P ₂ O ₅	Trace
Insol.	0.28
R ₂ O ₃ ^b	0.18
H ₂ O—	0.33
H ₂ O+	0.89

	100.03

^a Determined by J. G. Fairchild.^b Chiefly Fe₂O₃, limonitic impurity.

After deducting for gypsum, the ratio of CaO:MgO is 1.02:1.00.

Note. Since this paper was prepared, very similar examples of dolomite pseudomorphous after crystals of aragonite were collected by W. F. White, Jr., Water Resources Branch, Geological Survey, from just south of Dunlap, De Baca County, New Mexico. These crystals are slightly darker in color and do not show the twinning striations on the base. Otherwise they are very similar to the pseudomorphs from Wyoming.

NOTES AND NEWS

OCTAHEDRON-LIKE CRYSTALS OF CALCITE*

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Among the manifold habits shown by calcite, that of the combination of the base $c\{0001\}$ with a rhombohedron, yielding an eight-sided solid, is not common. Out of 2544 combinations illustrated in Goldschmidt's *Atlas der Kristallformen*,¹ only 26 show only the base and a rhombohedron. If the angle $(0001) (h0\bar{h}l)$ is close to 70° , and if the intersection of opposite faces is a point and not a line, then every face is a triangle and the crystal closely resembles an octahedron.



FIG. 1. Octahedron-like crystals of calcite from the Magdalena district, New Mexico. Enlarged two diameters.

In a suite of specimens from the Magdalena district, Socorro County, New Mexico, sent in for identification by the late Herman Wuestner of Cincinnati, is a small specimen (Fig. 1, enlarged two diameters) with white to gray crystals, about 4 mm. thick, which appear to be octahedra. It was thought by Mr. Wuestner that the calcite might be pseudomorphous after an isometric mineral like fluorite. Optical and chemical tests showed that the mineral was calcite with no indication of pseudomorphous structure. A little iron and manganese is present and the ω index of refraction is 1.669. Goniometric measurements established the crystallographical combination $c\{0001\}$ and $\eta\{04\bar{4}1\}$, using Dana's lettering.

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¹ *Tafeln*, Band 2, plates 2-155 (1913).

This combination of the base (two faces) and a steep rhombohedron (six faces) simulates an octahedron in shape, especially if the faces of the base and rhombohedron are triangular in shape and of equal size. Similar combinations have been noted on a number of minerals such as those of the jarosite group² with $c \wedge s \{02\bar{2}1\} = 70^\circ 53'$ and $s \wedge s' = 70^\circ 11'$ for jarosite, as coquimbite with $c \wedge o \{30\bar{3}2\} = 69^\circ 42'$, and $o \wedge o' = 71^\circ 22'$, and as tincalconite to which the name "octahedral borax" is commonly applied to the artificial salt, with $c \wedge r \{10\bar{1}1\} = 62^\circ 53'$.

A crystal of the octahedron-like calcite from the Magdalena district was adjusted on the two circle goniometer in polar position by cleaving off three bright smooth surfaces of $r \{10\bar{1}1\}$. The average ρ angle of the negative rhombohedron $\eta \{04\bar{4}1\}$ present on these crystals was measured as $76^\circ 38'$ (limits $74^\circ 04' - 77^\circ 42'$). The ρ angle for $\eta \{04\bar{4}1\}$ for calcite is $75^\circ 47'$, which is close to the octahedral angle of $70^\circ 32'$. The faces of c and η are to a large extent covered with drusy layers of later minute scalenohedral crystals of calcite, the faces of c more completely than those of η which are uneven and slightly rounded. The scalenohedron of the drusy layers is the positive form $E \{41\bar{5}6\}$ in G_1 position, or $\{21\bar{3}2\}$ in G_2 position, if they are in parallel growth with the octahedral-like crystals, as seems probable. The average of the measurements of the six faces of E is $\phi = 11^\circ 38'$, $\rho = 37^\circ 23'$ (calc. $\phi = 10^\circ 54'$, $\rho = 37^\circ 00'$).

The combination $\{0001\}$, $\{03\bar{3}1\}$ with a ρ angle for $\{03\bar{3}1\}$ of $71^\circ 20'$ would simulate an octahedron even closer. A rhombohedron with indices $\{0.23 \cdot \bar{2}3.8\}$, with $\rho = 70^\circ 25'$, would yield a combination with $\{0001\}$ which could hardly be distinguished from an octahedron ($70^\circ 32'$) by goniometric measurement.

Of the 26 combinations of the base and a rhombohedron for calcite listed by Goldschmidt, 80 per cent are a negative rhombohedron, distributed as follows:

$\{03\bar{3}2\}$	16 per cent
$\{02\bar{2}1\}$	28 per cent
$\{05\bar{5}1\}$	12 per cent
All others	24 per cent
	80 per cent

The combination $\{0001\}$, $\{04\bar{4}1\}$ is not listed by Goldschmidt.

The positive rhombohedra (20 per cent) are $\{40\bar{4}1\}$ and $\{10\bar{1}1\}$.

For dolomite, the combination of the base and a rhombohedron is of similar relative scarcity. Out of 102 combinations illustrated by Goldschmidt only two show such a combination, one with $\{10\bar{1}1\}$ and one with

² Particularly well shown by the equant octahedral-like crystals of plumbojarosite from the Tintic Standard mine, Dividend, Utah.

$\{40\bar{4}1\}$. Since Goldschmidt's *Atlas* was published, octahedron-like crystals of dolomite, up to $\frac{3}{4}$ inch in thickness have been found in New Mexico³ and George L. English kindly sent the writer a similar smaller black crystal of dolomite from Spain. The angle $c\{0001\} \wedge M\{40\bar{4}1\}$ was measured as $75\frac{1}{2}^\circ$ on the crystals of dolomite from New Mexico.

Of the four known localities of such octahedron-like crystals of dolomite, the rhombohedra are all positive, whereas in the majority of the occurrences for calcite (80 per cent), the rhombohedra are negative.

PROCEEDINGS OF SOCIETIES

THE CRYSTALLOGRAPHIC SOCIETY

A stated meeting of the Crystallographic Society was held November 17, 1941, in Room 4-345, Massachusetts Institute of Technology, Cambridge, Mass. Twenty-six members were present. The proposed Constitution and By-laws were discussed and approved, and the organization of the Society was placed on a formal basis. The following officers were elected for 1941-42: Professor Martin J. Buerger, President; Professor Harry Berman, Vice-President; Dr. Clifford Frondel, Secretary-Treasurer. At the close of the business meeting, Mr. Joseph Lukesh spoke of work carried on jointly by him and M. J. Buerger on "The Tridymite Problem." The talk was followed by a lively discussion bearing on the geological implications of the unusual thermal behavior reported, and on the mechanism of formation of super-structures based on silica frameworks. The speaker's abstract of his talk follows:

THE TRIDYMITE PROBLEM

Crystals of tridymite from Plumas County, California, have been investigated by the Weissenberg method. The diffraction symmetry of the low form is *mmm*. It is based upon a face-centered orthorhombic lattice, the cell having the following dimensions:

$$a = 9.91 \text{ \AA}$$

$$b = 17.18 \text{ \AA}$$

$$c = 81.57 \text{ \AA}$$

Possible space groups include *Fmm*, *Fmmm* and *F222*. The abnormal length of the *c* axis prompted investigation of tridymite from other localities. A sample from San Cristobal, Mexico, was found to have the same *a* and *b* axes, but the *c* axis was one-half as long. The *c* axis rotation patterns of the two materials were substantially identical as regards distribution and relative intensities of all reflections, except that the intermediate layer lines found on the pattern of the Plumas County material were missing on the pattern of the San Cristobal material.

Spectroscopic and chemical analyses of the Plumas County tridymite indicate a high impurity content, with an empirical formula approximating $\text{NaCaAl}_3\text{Si}_{15}\text{O}_{36}$. The presence of the impurity atoms is believed to be the cause of the doubled *c* axis.

Attempts were made using a controlled-temperature Weissenberg camera to locate the two inversions of tridymite at 117°C . and 163°C . as determined by Fenner from thermal observations on pure, artificial material. The Plumas County material inverted directly from the low form to the high form at 127°C . with no evidence of a middle form. The tridymite from San Cristobal showed two inversions, low to middle at 121°C . and middle to high at 135°C . The absence of a middle form in the case of the Plumas County material and the

³ *The Mineralogist* (Oregon), 7, 385 (1939).

smaller temperature range than expected in the case of the San Cristobal material are attributed to the presence of impurities.

Weissenberg patterns of the Plumas County tridymite were taken just above the inversion. In addition to the pattern to be expected from the hexagonal silica framework, there was found superimposed an orthorhombic pattern of satellite reflections which varied in their distribution in a definite manner with temperature, but not with time. The sequence was not reversible, and once it had been carried through to completion, it could not be obtained again on the same crystal. A similar, but less complicated, sequence was found using the material from San Cristobal. The presence and the behavior of the satellite reflections can be explained by the migration of the impurity atoms from positions taken at the time of formation of the crystals, when electrostatic forces only were satisfied, to positions taken during heating that are more compatible with packing requirements. It appears that both the Plumas County and the San Cristobal tridymite must have formed below 121° and 127° C., respectively, inasmuch as the temperature inversions are irreversible.

CLIFFORD FRONDEL, *Secretary*

NEW MINERAL NAMES

Cadwaladerite

SAMUEL G. GORDON: Cadwaladerite, a new aluminum mineral from Cerro Pintados, Chile. *Notulae Naturae Acad. Nat. Sci. Phila.*, no. 80, 4 pp. (1941).

NAME: For Mr. Charles M. B. Cadwalader, President of the Academy of Natural Sciences of Philadelphia.

CHEMICAL PROPERTIES: A basic aluminum chloride. Analysis by William Pitman on 0.43 g. gave: Al_2O_3 27.50, CaO 2.07, Na_2O 1.85, K_2O 0.90, Cl 22.96, SO_3 0.82, H_2O — 25.13, $\text{H}_2\text{O} +$ 24.99; sum 106.22 (given 106.32) less ($\text{O} = \text{Cl}_2$) 5.18 = 100.94. After deduction of gypsum, halite, KCl and CaCl_2 , this gives $\text{AlOCl} \cdot 5\text{H}_2\text{O}$ or $\text{Al}(\text{OH})_2\text{Cl} \cdot 4\text{H}_2\text{O}$. This mineral is somewhat less hygroscopic than the accompanying halite.

PHYSICAL PROPERTIES: Amorphous, optically isotropic with n (Hg yellow light) = 1.513 (variable). Color lemon yellow (Ridgway); transparent to translucent; luster vitreous. Fracture conchoidal. Gr. 1.66 (by immersion in benzol-bromoform mixtures).

OCCURRENCE: Found as grains and small masses in colorless, granular and columnar halite on the old dumps of Cerro Pintados, Province of Tarapaca, Chile. This is the type locality for pickeringite, tamarugite and trudellite. Iron sulfates (botryogen, copiapite, etc.) also occur there.

DISCUSSION: X-ray study would be desirable. It seems probable that this mineral, like many others which are "amorphous" by optical tests, will prove to be crystalline.

MICHAEL FLEISCHER

NEW DATA

Slavikite, Butlerite

SAMUEL G. GORDON: Slavikite, butlerite, and parabutlerite from Argentina. *Notulae Naturae Acad. Nat. Sci. Phila.*, no. 89, 8 pp. (1941). Slavikite occurs with other Fe sulfates at the Mina "Santa Elena" (see sarmientite, above). The crystals were found to be hexagonal, rhombohedral, with $c = 1.389$. A new analysis gives the formula $\text{MgFe}(\text{SO}_4)_4(\text{OH})_3 \cdot 18\text{H}_2\text{O}$. The magnesium content was apparently overlooked in the original analysis. Butlerite occurs as oriented intergrowths with parabutlerite. Crystallographic study shows butlerite to be monoclinic, not triclinic.

M. F.